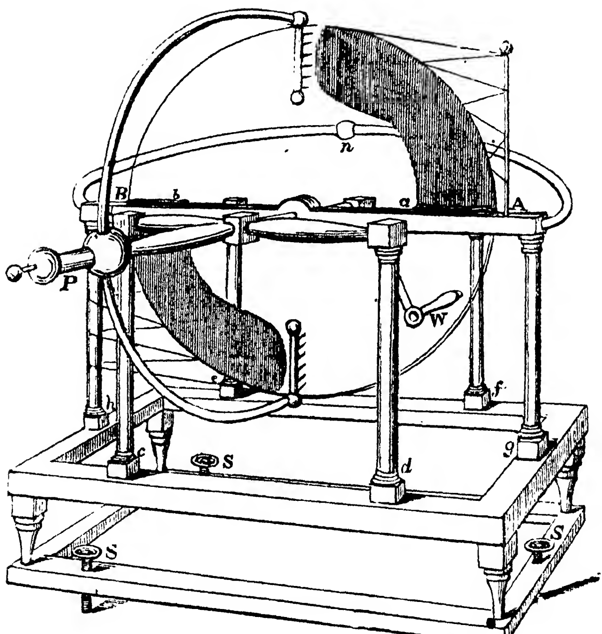

Glass Plate Electrical Machine.—See p. 63.

RUDIMENTARY

ELECTRICITY:

BEING

A CONCISE EXPOSITION OF

THE

GENERAL PRINCIPLES OF ELECTRICAL SCIENCE,

AND

THE PURPOSES TO WHICH IT HAS BEEN APPLIED.

BY

SIR W. SNOW HARRIS, F.R.S., &c.

Third Edition.

WITH CONSIDERABLE ADDITIONS, INCLUDING EXTRACTS FROM THE CAVENDISH PAPERS.

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PREFACE.

Having consented to prepare a small Treatise on Electricity for Mr. Weale's Series of Rudimentary Works, the author of the present volume has endeavoured to confine himself within the limits of such a production as may be read with advantage by those engaged in the study of Physical Science. Electricity has, however, within a comparatively recent period advanced so rapidly and proved so fertile in discovery, that it is by no means an easy task to bring all that relates to this department of natural knowledge within the circumscribed space necessarily allotted to a Rudimentary Work. What the author has, therefore, principally attempted to give, is a sound, practical, and theoretical view of the subject, involving broad general principles, without abstruse detail, commencing with the simplest facts, and illustrating them by easy and accessible experiments.

Although the scientific reader must expect to find in the following pages much with which he is already familiar, yet the author is encouraged to hope that this little work will be found to contain many new facts and illustrations not altogether unworthy of attention.

Through the kindness and liberality of the Earl of Burlington, the author has been able to introduce into this new

edition many valuable extracts from unpublished manuscripts of the Honourable Henry Cavendish, one of the most distinguished ornaments of British science, and whose electrical researches form a prominent feature in the 'Transactions of the Royal Society' for the year 1770. It appears by these manuscripts, confided to the author's care, with permission to make such use of them as he might think beneficial to science, that Mr. Cavendish had foreseen and actually arrived at many important results in electricity which afterwards engaged the attention of those profound Mathematicians and Philosophers who have so industriously pursued this branch of Physics, and many of which subsequently appeared in the Memoirs of the Royal Academy of Sciences of France.

W. Snow Harris.

P.S. The present volume having been extended, by the addition of the valuable extracts above referred to, beyond the limits of a 1*s*. volume, the Publisher prefers making the price 1*s*. 6*d*. instead of converting it into a double 2*s*. Part; which he trusts will be more satisfactory to the public.

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Phenomena observable in subjecting certain Substances to a peculiar species of Excitation by Friction—Origin of Electrical Terms—Electrics and Conductors—Insulation, Attraction, and Repulsion—Positive and Negative Electricity—Induction, or Electrical Influence—Other sources of Electrical Excitation—Manipulation.

1. It may be esteemed as a deeply interesting and wonderful fact, that the most active powers of nature are at all times present to us, although in a state not always cognizable by our senses, and hence termed *latent:* the slightest change, however, in the existing circumstances will frequently render these powers active, and we become as it were immediately surrounded by the most astonishing effects. This observation is more especially exemplified in the development of that class of phenomena which we term *electrical;* the unknown agency upon which they depend being sensible of the most trivial change in its physical relations to the particles of common matter. Many substances, for example, when merely pressed into close contact and subsequently separated, tend not only again to approach each other, but they also display that peculiar effect which we term *Attraction,* in respect of other substances. In the falling of a stone, and in the tendency of ferruginous particles towards a certain ore of iron known as the loadstone or magnet, we recognize the presence of other physical forces, the precise nature of which is at present involved in obscurity.

2. *Early knowledge of Electrical Attraction.*—That peculiar and invisible agency, then, which we term Electricity, is one

of those hidden and mysterious powers of nature which has thus become known to us through the medium of effects: our first acquaintance with it appears to have arisen out of a curious but simple fact, noticed full 600 years before the Christian era. Thales, of Miletus, a celebrated Greek philosopher, the founder of the Ionic Philosophy, observed as a remarkable property of amber, its power of attracting light particles of matter on being subjected to a peculiar kind of excitation by friction, and with which he is said to have been so struck, that he imagined the amber to be endowed with a species of animation. Theophrastus, about 300 years before the Christian era, observed a similar property in a hard stone termed the *lyncurium*, now supposed to have been the tourmaline, which he says will not only attract light straws and sticks, but even thin pieces of metal. Pliny and other naturalists also notice this property of amber; and a similar property is said to have been discovered at an early period in agate. In the present state, however, of this department of science, we no longer confine our views to a particular instance of electrical action limited to a few conditions only, but consider the development of electricity as arising out of a great variety of operations and circumstances, both natural and artificial,—such as the contact of various substances, friction, pressure, cleavage, and other mechanical processes, changes of temperature and form, as in the case of liquefaction, and other natural processes of that kind, together with chemical and certain forms of magnetic action; these will all superinduce upon bodies an attractive power of a greater or less amount.

3. *Origin of Terms.*—The attractive property developed in amber by the process of friction may be considered as the source of the nomenclature of this branch of science. The Greek word expressive of amber being ἤλεκτρον (electron), in Latin Electrum, the unknown principle, or element, with which Thales supposed it to be animated has been termed Electricity. As our knowledge of such phenomena advanced, and

other substances were observed to possess similar properties, they were considered as being *amber-like,* were said to be *electrical,* and were hence termed Electrics.

In a similar way, when any given substance was caused to exhibit attractive powers by the simple process of friction, it was said to be *electrified,*—the process itself being termed *electrical excitation,* and the attractive force *electrical attraction:* any contrivance also for the mere exhibition of such force has been termed an *Electroscope,* whilst other contrivances for the more precise measurement of the power itself have been termed *Electrometers;* so that the common terms employed in this department of science are all based on the Greek and Latin terms signifying amber.

4. *Electrical Excitation.*—The phenomena attendant on electrical excitation by the process of friction are easily observed; it is only requisite to bring the excited substance near any light body, such as a downy feather, the pith of elder, or a fragment of metallic leaf, in which case the attractive effect becomes immediately apparent, more especially if these substances be dry and delicately suspended. If the excitation be powerful and be carried on in a dark room, faintly luminous flashes, and sometimes luminous sparks, attended by a weak crackling noise and a peculiar odour, may be observed to arise from the surface of the excited body.

Exp. 1. Let an ordinary stick of sealing-wax or a roll of brimstone be freely rubbed with a piece of dry woollen stuff, or soft white silk; it will become attractive of light particles of matter, such as fragments of metallic leaf, a downy feather, or small pieces of paper.

Exp. 2. Take a dry tube of glass, about an inch in diameter and about eighteen inches in length; rub the tube freely from one end to the other, through a dry soft silk handkerchief, held in the hand: small pencils of light and faintly luminous flashes and sparks, attended by a subdued crackling noise and a peculiar smell, will appear in the dark to dart from the surface of the glass, producing a marked sensation when held near the

hand or face. If the tube be now presented to any light body, a powerfully attractive force will appear to be exerted by the tube. Downy feathers, fragments of cotton wool attached to delicate threads, small balls turned out of elder-pith, fragments of metallic leaf, leaf gold more especially, are the substances best adapted to such experiments.

These effects will be more sensibly produced if the tube be gently warmed by passing a current of warm dry air through it, and if the silk used to excite it be touched over with a compound of tin and sulphur, termed 'aurum musivum,' * or mosaic gold, used by statuaries and painters. The rough side of oiled silk, oiled only on one side, will, when rubbed over with this substance, produce a powerful effect.

5. Although the list of electrical bodies was in the remote periods of science extremely limited, being principally confined to amber, jet, and agate, yet in more recent times it has become so general as to include almost every known substance, as being susceptible in a greater or less degree of electrical excitation. The substances, however, more especially termed *idio*-electrics, that is to say, those which under ordinary circumstances readily evince electrical properties by friction, may be brought within the following limits:

TABLE I.—LIST OF ELECTRICAL BODIES.

Shell lac—brimstone—amber—jet.

Resinous bodies of every kind, including pitch and wax.

Gums of every kind, including camphor and caoutchouc.

Gun-cotton.

Glass and all vitreous and vitrified substances.

The diamond, agate, and most other precious stones.

Tourmaline, and other crystalline transparent argillaceous and silicious gems and stones.

Bituminous substances.

* This composition is prepared chemically by first saturating the tin and sulphur with mercury and a little sal-ammoniac, and then subjecting the amalgam to a sand heat. It may be obtained readily at any chemist's.

Silk of every kind and form.

Dried animal furs and skins—hair—wool—feathers—paper—porcelain.

Turpentine and various oils and fatty fluids.

All dry gases.

Atmospheric air.

Steam of high elasticity.

Ice at 0° of Fahrenheit.

The modern substance termed gun-cotton is not the least powerful of these electrics; when made in large quantity, it retains the form of the fleece or sheet of cotton wool from which it is made. If the fleece be well dried, then on drawing it through the hand we obtain a perfect cloud of sparks.

6. *Friction the remote but not the immediate cause of attraction.*—The state of excitation of any of these electric substances appears to be entirely confined to the parts immediately under the points of contact of the rubber and the surface to which the friction is immediately applied: even here it is for the moment in a latent or insensible state, so long as the contact with the rubber is preserved; it is only on the separation of the two bodies that the excitation is apparent. Thus if a square of common window glass be subjected to friction on a portion of one of its surfaces, that portion, together with a similar portion of the opposite surface immediately under the rubber, will, on withdrawing the rubber, exhibit electrical excitation, but no other part of the glass will do so.

Exp. 3. Place a square of window glass, A B, fig. 1, made very dry, and slightly warm, upon two wine-glasses, as supports; and apply to its upper surface a flat circular rubber R, which may consist of a common cork bung, cut

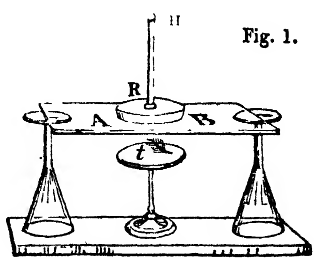


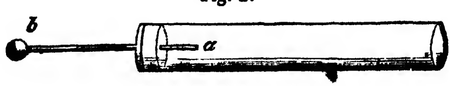
Fig. 1.

evenly and flat, and covered with silk, and having a rod of wood or metal H, fixed in its centre as a handle. Place any light substance *t* immediately under the rubber, and about an inch, more or less, from the glass. A fragment of Dutch gold, or a light feather, answers very well. Turn the circular rubber carefully round so as not to derange its place on the glass. Not the least attractive effect will be observed on the light body *t* during the friction. Let the rubber be now raised off the glass, and the substance *t* will be vigorously attracted, but only by that portion of the glass which has been rubbed. If the rubber be prepared as in Experiment 2, the attractive effect will be vigorous, and exerted on the gold fragment at a considerable distance; and if the glass and rubber be fixed in a frame of wood, the results are more conveniently obtained.

7. *Discovery of electrical conduction.*—About the year 1729 an important discovery resulted from some attempts of Mr. Stephen Grey, of the Charter-House, in London, to render metallic substances attractive by friction. He completely failed in these attempts, but he found that although these substances were not excitable in the ordinary way, yet they might acquire an attractive power by placing them in communication with an electrified body.

Exp. 4. *Communication of electricity to non-excitable substances.* — Let a stout brass wire, about $\frac{1}{8}$th of an inch in diameter and a foot in length, be passed through a common cork, fixed in one extremity of the glass tube employed in Experiment 2, so as to project about 2 inches within the tube. Fix a small wood or brass ball on the projecting extremity of the wire, as at *b*, fig. 2, and excite the tube in the way before

Fig. 2.

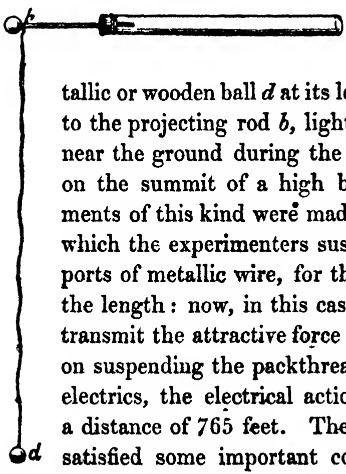


described (4). The wire *a b* and the ball *b* will both become attractive of light bodies in common with the tube, and the

excited electricity will be communicated to the ball and wire from its inner surface, and with so much force as to cause luminous sparks to pass from the ball upon the *finger* or other conducting body placed near it. A similar application of a metallic wire and ball to any other electric is attended with the same result. When applied to solid electrics, such as sealing-wax, it may be inserted immediately into their substance.

8. This communication of excited electricity to non-electric substances was found, on further inquiry, to extend through a considerable length of such substances. Thus, when a very long wire, *b d*, fig. 3, having a metallic or wooden ball *d* at its lower extremity, was attached to the projecting rod *b*, light bodies were attracted by it near the ground during the excitation of the glass tube on the summit of a high building. The first experiments of this kind were made with common packthread, which the experimenters suspended horizontally by supports of metallic wire, for the convenience of increasing the length: now, in this case it was found impossible to transmit the attractive force through the thread, whereas on suspending the packthread by *cords of silk* or other electrics, the electrical action was transmitted through a distance of 765 feet. These silk cords, therefore, had satisfied some important condition of the experiment. When a silk line, however, was substituted for the packthread, the electrical excitation of the tube was no longer apparent in the ball at the remote extremity, in whatever way it was suspended. From this it became apparent, that the class of substances termed electrics had not only the property of electrical excitation, but that they had also the power of confining or imprisoning, as it were, the communicated electricity upon other bodies, in which it could not, under the same circumstances, be so excited: on the other

Fig. 3.



hand, the non-electric substances allowed the excited electricity to pass off to the walls of the building and to the ground. Hence arose a distinct series of phenomena dependent on what has since been termed *Electrical Conduction,* giving origin to a new classification of substances considered as conductors of electricity.

9. The substances which properly come under this *conducting* or *non-electric* class are principally the following:

TABLE II.—LIST OF ELECTRICAL CONDUCTORS.

Every metallic substance known.
Well-burned charcoal.
Plumbago.
Concentrated and diluted acids and saline fluids.
Water and moist vegetable matter.
Living animal matter.
Flame—smoke—steam.

10. The distinctive difference in the conducting and non-conducting property of bodies may be readily illustrated in the following way:

Exp. 5. Excite the glass tube and wire employed Exp. 4, and bring the ball of the wire into contact with any of the substances mentioned in Table I., termed *electrics,* such as a rod of glass, a stick of sealing-wax, or brimstone. If these substances be made perfectly dry, the attractive power of the ball and wire, together with the tube, will not be in any sensible degree impaired. Let the electrified ball now touch the walls of the room or other conducting substance communicating with the ground: the attractive power will instantly vanish.

It is evident from these facts that all electric substances (5) are *non-conductors* or *insulators,* as they are also appropriately termed; whilst, on the other hand, *non-electric substances* are transmitters or conductors of electrical action.

11. *Insulation.*—When, therefore, any conducting substance

is placed on an electrical support, such as a rod of glass or shell lac, it is considered to be insulated, and is termed an *insulated conductor:* when electrified by contact with any excited or other electrified body, it is said to be *charged.*

The best insulating substances are of the vitreous and resinous class, Table I., such as shell lac, brimstone, dry glass, vitrified and crystalline bodies. To these may be added silk.

The best conducting substances are principally metallic bodies, saline fluids, and common charcoal.

12. It should, however, be here understood, that modern researches, especially those of Faraday, lead us to conclude that there are really no substances which perfectly conduct or perfectly obstruct electrical action. The *insulating* or *conducting* power is, in fact, a difference of degree only; still the extreme differences are so great, that if classed in relation to such differences, those at the extremes of the series admit of being considered the one as insulators, the other as conductors, whilst the intermediate terms are made up of substances which may be considered as imperfect, taken as either. Conversely, every substance is capable of excitation by friction; yet the differences in this respect are so great as to admit of some bodies being called electrics and others non-electrics, with an intermediate class between these extremes, which may be termed imperfect electrics.

Series of conductors and insulators.—Metals and concentrated acids are found at the conducting extremity of such a series,—shell lac, brimstone, all vitreous and resinous bodies, at the other or electric extremity; whilst the imperfect or intermediate substances comprise such matter as common earth and stones, dry chalk, marble, porcelain, paper, and alkaline matter.

13. *Electrical Repulsion.*—The attractive power evinced by any electrical body in a state of excitation, although the first and usually the most evident electrical effect, is not the only force which seems to result from this curious condition of

common matter. On a closer examination of the phenomena, a new class of facts present themselves, of remarkable interest. If the excitation be considerable, and the attracted body insulated, it will, after being drawn into contact with the electrified substance, rebound from it, with great violence, as if repelled by some new power, and will not be again attracted until it has had conducting communication with the earth, or with some other mass of matter capable of reducing it to its original condition before the contact, or very nearly so. The attractive force becomes, in fact, superseded by an opposite or repulsive power, and thus two kinds of force appear to be obtained.

Exp. 6. Attach a slip of metallic leaf, about half an inch in width and 4 inches long, to a short and thin slip of writing paper, which is easily done by a little moisture from the lips. Fix the paper to the extremity of a stick of common sealing-wax, or a slender rod of glass coated with sealing-wax, as represented in fig. 4: present this leaf, thus insulated by the wax, to the metallic ball of the excited tube described in fig. 2: the leaf, after being vigorously attracted, will instantly on contact with the ball appear to be repelled, and will not be again attracted until reduced to its original state, either by contact with the earth or with some other unelectrified mass. A simple reed, suspended by a short cotton or silk thread, may be used for this purpose with advantage.

Fig. 4.

A test or trial leaf or reed, when thus prepared and insulated, constitutes an extremely good electroscope, and is well adapted for the exhibition of simple electrical phenomena. Leaf gold, and silver leaf, may be occasionally employed for minute forces, but these cannot be managed without some difficulty. The best kind of metallic leaf for ordinary purposes is a coarse kind of leaf termed Dutch metal. The white metal is often the most compact, but the yellow metal is sometimes preferable.

Exp. 7. *Electrical attractions and repulsions.*—Excite a tube of glass as in Experiment 2, and bring it near a small

ball of cork or elder-pith, resting on a table. The ball will appear to bound from the table towards the tube, from which it will be as instantly repelled; on touching the table it will be again attracted, and thus a rapid play of what appears to be a series of attractions and repulsions may be maintained for some time.

In all these experiments the excitation requires to be vigorous, and this may always be insured by the means before described (4).

14. On a further examination of these attractions and repulsions, we find a most important relation of electricity to common matter, leading to the conclusion that in every case of electrical excitation, as well as in every other instance of electrical action, two equal and opposite forces or powers are called into play. These, when combined, condense or saturate each other, and thus neutralize the free action of either, as observed in the phenomena just described.

Exp. 8. *Two kinds of electrical power.*—Let a simple leaf, such as that employed in the last experiment, be made repellent of an excited glass tube, fig. 2 (7), so as to be thrown freely off it. Whilst in this state, present it to an excited roll of brimstone or sealing-wax. The leaf will appear to be vigorously attracted by this substance. Conversely, present the leaf first to the excited brimstone, and when made repellent of that, to the excited glass,—a powerful attractive effect will ensue.

It is here evident that one of these substances will, under given conditions of excitation, attract an electrified body made repellent of the other. We are indebted to M. Du Fay, an intelligent French philosopher, for this beautiful fact, whose memoirs, published in the 'History of the Academy of Sciences' from 1733 to 1737, may be considered as having largely contributed to the progress of electricity. Symmer, an English philosopher, in 1759, still further advanced Du Fay's discoveries, and very completely established the fact of opposite electrical forces.

15. *Vitreous and resinous,*—or *positive and negative electricity.*—We are led, then, from these interesting facts to infer the existence of two opposite electrical or elementary states of excitation in which forces are developed attractive of each other; these forces were supposed by the more early inquirers to depend on two different kinds of electricity, which they termed *vitreous* and *resinous* electricities,—as being derived, the one from excited vitreous bodies, the other from excited resinous bodies: subsequent investigations, however, as we shall presently see, show, that both these hypothetical electrical elements may be obtained from the same electric, merely by changing the substance employed to produce the friction: hence, as involving less assumption, it has been agreed to designate the opposite electrical states of which these terms are really expressive by the common positive and negative signs employed in arithmetic and algebra, calling the one *positive* or *plus,* and the other *negative* or *minus;* the positive sign + being given to the vitreous excitation, as developed in the friction of glass by silk; the negative sign — being appropriated to the excitation of resinous bodies by silk or woollen stuff.

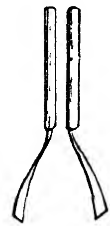
The terms positive and negative an arbitrary selection.—It is to be understood here, however, that the appropriation of these terms is altogether a matter of arbitrary selection. When any substance, therefore, evinces vitreous electricity, it is said to be electrified positively, or plus + : when it evinces resinous electricity, it is said to be negatively electrified, or minus — : when unelectrified, or in its ordinary state, it is said to be neutral.

A glass tube and wire, such as are described in Exp. 4, page 6, are an efficient and convenient arrangement for obtaining vitreous or positive electricity; and if the tube be well varnished over with a solution of shell lac in rectified spirits of wine, laid on the previously warmed glass, resinous or negative electricity may then, by exciting the surface with dry woollen stuff or soft white silk, be obtained from the wire and ball, in a similar way: the same result is obtained by making the

tube sufficiently hot, and rubbing it over with sealing-wax, so as to give the surface a thin coating.

16. From these phenomena it may be inferred, that substances in dissimilar states of electricity, that is, the one +, the other —, *attract* each other. Substances in similar electrical states, that is, both + or both —, *repel* each other. The two following experiments are easy and simple illustrations of these elementary electrical facts.

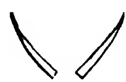
Fig. 5.



Exp. 9. *Similar electricities repel—opposite electricities attract.*—Prepare two similar test leaves of metal, as in Experiment 6: let each be made repellent of an excited glass tube or of an excited roll of brimstone or sealing-wax: oppose these electrified leaves fairly to each other, and they will immediately diverge, as represented in the annexed fig. 5.

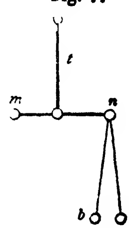
Exp. 10. Make one of the trial leaves repellent of excited glass and the other repellent of excited wax or brimstone; oppose them, as before, and they will immediately converge and approach each other, as represented in fig. 6.

Fig. 6.



17. Threads of cotton, or otherwise light reeds of straw, terminating in small balls of elder-pith, may be employed in these experiments with advantage. They should be attached to fine rods of glass, shell lac, or sealing-wax: the reeds may be hung up by filaments of linen thread, to allow of free motion. Two very light straws *a b*, suspended on a short metallic wire *m n*, fig. 7, insulated by a handle of light glass rod *t*, forms an extremely convenient electroscope; since on touching an electrified body with the extremity *m* of the rod, the reeds will diverge with the electricity of that body; and will again close on

Fig. 7.



a similar application to any substance charged with the opposite electricity, and reciprocally will not close or will separate further by the electricity of a body charged with the same electricity.

18. In treating of the phenomena of excitation we have as yet considered the development of one only of the two electrical forces; on a closer examination, however, it is found that both forces are produced, although only one is usually apparent. This may be made evident by insulating the rubber, that is, the body with which the electric is said to be excited; in this case the rubber will be found also attractive of light bodies, and its electrical state will be precisely the reverse of that of the excited body. The reason, therefore, why this force is not apparent in ordinary cases of excitation, is in consequence of the rubber being usually in contact with conducting matter, such as the hand, by which its electricity is neutralized through conducting communication with the earth (8).

Exp. 11. *Both electricities produced in every case of electrical excitation.*—Wrap a broad slip of soft silk, or a wide silk ribbon, round a rod of glass or sealing-wax, to serve as an insulating handle: apply the roll thus produced as a rubber upon a strip of common window glass of equal width, made perfectly dry and a little warm: after slight friction, examine both the silk and the glass; each will attract light substances, but they will be in opposite electrical states, as is seen by the one attracting where the other repels. This may be shown, as in the last experiment, by an insulated strip of metallic leaf, which may be suspended from some convenient support. The experiment may be repeated with a small roll of dry woollen stuff and a stick of sealing-wax or brimstone.

19. *Opposite electricities dependent on the nature of the exciting surface.*—The kind of electricity resulting from friction appears to depend on some peculiar condition of contact between the rubbed surfaces. Thus a rod of glass, rubbed by white silk, evinces that peculiar state of electricity which it has been agreed to call *vitreous* or *positive;*

but when the glass is rubbed against the back of a cat, it evinces what has been called *resinous* electricity; that is to say, an opposite or *negative* state of electricity. Glass rubbed with silk is positive, but sealing-wax rubbed with the same silk is negative. Conversely, silk rubbed with glass becomes negative, but rubbed with sealing-wax is positive. It is easy for the student to satisfy himself of these facts by very simple experiments. Electrify the trial leaf, fig. 4, either positively or negatively (15). Rub a stick of sealing-wax on warm coarse brown paper, then if the leaf be positively electrified, the wax will attract and the paper repel it. If a warm glass be rubbed on the brown paper, the glass will be positive, as shown by its repelling the plus leaf, whilst the same leaf will be attracted by the negative paper. Friction of sealing-wax on a silk ribbon renders the wax minus and the ribbon plus. If two silk ribbons, one white and the other black, be made quite warm, placed in contact, and then drawn quickly through the closed fingers, they will on separation be found highly attractive of each other; the white will be +, and will repel the plus leaf; the black will be —, and attract it. It is a remarkable fact, that of the numerous substances examined in this way, the back of a cat is + to every other. Then we have smooth glass + to every other, although — to the cat-skin. Sealing-wax is — to most other substances, but when rubbed with metals it is +.

The student will perceive from these facts, that the same substance may acquire both kinds of electricity, and may be + by friction with one body, and — by friction with another.

If the trial leaf be negatively charged, the same results will be arrived at, but the attractions and repulsions will be reversed.

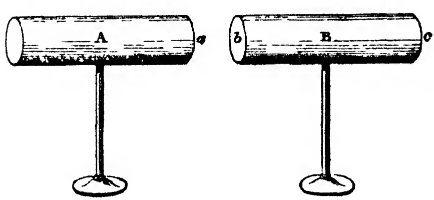
The trial leaf or other single electroscope used in these experiments is most conveniently suspended by means of the stand and horizontal arm shown in fig. 19, page 35.

20. *Electrical influence.*—These first or more elementary

facts being understood, we are prepared to enter upon a new class of phenomena, remarkable for their great interest and importance in the progress of electrical discovery. We have hitherto confined our attention to the attractive and repulsive powers developed in bodies either by a direct excitation (4), or by immediate communication (7); but there is yet another form of electrical charge to be considered, depending on the influence of excited bodies upon neutral conducting bodies, and exerted at very sensible and even considerable distances. This influence has been termed *Electrical Induction,* and the resulting effect, *Induced Electricity.*

Exp. 12. Insulate upon supports of varnished glass two small cylinders of wood or metal, A B, fig. 8, from 3 to 5 inches in length and about 3 inches in diameter, and terminating in flat faces: place these cylinders within an inch or more of each other, and in a right line, as represented in the figure. Excite freely the glass tube and wire (fig. 2, page 6), and communicate by repeated contacts of the ball an electrical charge (11) to one of these conductors A. Present now to the distant extremity *c* of the cylinder B the slip of metallic leaf or other light substance, as described in Ex-

Fig. 8.



periment 6, page 10: it will be immediately drawn towards it. Present the leaf also to various parts of the cylinder B, between the extremities *b c*: the attraction will diminish considerably as we pass from the distant extremity *c*, until it becomes nearly nothing.

If we withdraw the electrified body A, these phenomena

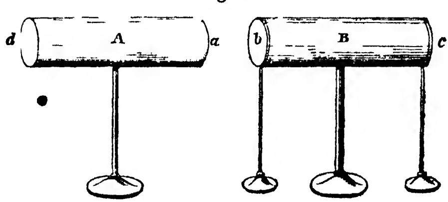
are no longer apparent, thus proving that the electrified state of the cylinder B was an induced or temporary condition, depending on the influence of A, whilst operating upon it at a distance.

Exp. 13. Place the two cylindrical conductors near each other, as before, and communicate a charge to one of them A; make the test leaf repellent of A by contact with it, and then present it to the distant extremity *c* of the cylinder B. It will be also repellent of that extremity, showing that the electrical states are the same, but the repulsive effect will diminish considerably as we approach the near extremity *b*, where it will appear to be nearly lost.

21. If the precise condition of the conductor B, whilst under the influence of the charged conductor A, be carefully investigated, its extremities *b* and *c* will be found actually in opposite electrical states; for although one of these only is apparent in the distant extremity *c*, whilst under the influence of the charged conductor A, yet by a slight variation in the experiment the opposite electricity may be also discovered.

Exp. 14. Let the terminating faces *b c*, fig. 8, of the cylindrical conductor B consist of thin slices of about $\frac{1}{8}$th of an inch or more in thickness, supported upon slender glass rods, as shown in figure 9, and applied so as to fit closely against the

Fig. 9.



opposite ends of B. Charge cylinder A as before (Exp. 12), and remove the terminating face *b* by its insulating rod whilst under the induction of A. This face *b* will now attract the trial leaf when the leaf is repellent of the charged cylinder A,

and repel it when the leaf is attractive of A, thereby showing that it is in an opposite electrical state; that is to say, if A be charged positively, *b* will be charged negatively; and if A be negative, *b* is positive (16). Proceed now to remove in a similar way the distant face *c*, we have then the converse of this result (Exp. 13); that is to say, the face *c* will be found, as before, attractive of the trial leaf when that leaf is attractive of A, and repellent of it when repellent of A; thereby showing that its electrical state is the same (16): hence its being formed of a thin slice, and applied as an extremity of the cylinder A, does not at all interfere with the result.

It may not be out of place here to observe, that the electrical disturbance in the near face *b* will be most strikingly shown if removed under the influence of A when the cylinder B is extended in length, or is in conducting communication with the earth.

This electrical disturbance by induction, although more particularly observable in the neutral conductor, is, however, not exclusively confined to it: on further investigation we find a sort of reflected induction on the charged body itself, causing a considerable change in its previous condition.

Exp. 15. Charge the cylinder B, and observe by the trial leaf the repellent effect of each of its terminating faces; after which oppose to it the conductor A in a neutral state, placed in conducting communication with the ground. Under these conditions, the repellent effect towards the distant extremity *c* will be considerably diminished, and towards the near extremity *b* evidently increased; and if we remove each of the terminating faces, as before, by their insulating supports, the repellent power of the near face *b* will be found greater than that of the distant face *c*, which face may become under some conditions quite neutral, and evince even an opposite or negative state.

22. *Specific inductive capacity.*—In these preceding experiments we have supposed the inductive action to take place

through air,—a similar result, however, is apparent when any other electric substance (5) is interposed between the two bodies, but with this important distinction, that many of these substances facilitate the progress of electrical influence in a greater degree than others. Let, for example, a delicate trial leaf, sheltered by a glass jar, fig. 22 (41), communicate with the surface *c* of the body B, fig. 8 (20), and suppose B, as before, to be under the influence of A, the intervening electric being air; then if a plate of clean shell lac or brimstone be interposed between the near surfaces *a* and *b*, that leaf will be more readily attracted by a body brought near it than before. This difference in the power of electrics to facilitate the progress of electrical influence has been termed by Faraday, to whom we owe the discovery, 'specific inductive capacity.' The question is one of singular interest, and is still open to further investigation. The difference in the specific inductive capacity of air and shell lac is as 1 : 1·6 nearly.

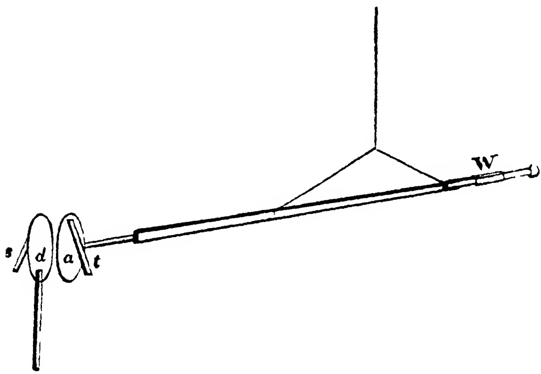
23. This peculiar kind of electrical action, termed *Induction*, appears essential to the phenomena both of attraction and repulsion (2) (13): it is invariably attendant on both, and in all probability precedes them; that is to say, in every case of electrical attraction or repulsion the bodies are first rendered attractable or repellent, and then attracted or repelled; and without this previous preparation, neither of these effects are produced. Thus it is found that the attraction of an excited electric, or of a charged conductor, is less forcible upon electrics little sensible of induction, than upon conductors highly susceptible of such change.

Exp. 16. *Attraction and repulsion attendant on induction.*—Cover a small sheet of writing paper, on each side, with smooth gilt paper, so as to produce, when pasted and dry, a stiff plate; cut out a circular disc of about 3 inches in diameter, and attach to one side of it a slip of metallic leaf, so as to hang freely about its surface, as in the annexed fig. 10, which is easily

Fig. 10.

done by uniting the leaf to a thin slip of cork, cemented to the disc by a little strong paste; attach this disc to a thick filament of glass, at right angles to the direction of the leaf; by means of a little sealing-wax, fix the glass in the extremity of a light arm of deal, suspended by a fine thread of silk from the ceiling, as shown in fig. 11; balance the system by

Fig. 11.



means of a small loop for suspension, and a sliding weight w, as in the figure. The system being thus free to move about a centre, present to the disc *a* an insulated electrified disc *d*, charged either positively or negatively (15): the leaf *t* will be observed to spring away as it were from the disc, and remain divergent from it: and if a similar trial leaf *s* be attached to the opposite surface of *d*, and be also in a state of divergence, that leaf, on approaching the neutral disc *a*, will tend to collapse, at which instant the bodies will appear to attract each other.

In this experiment we observe, 1st, The divergence of the trial leaf *s* of the disc *d* by the charge conveyed to it (16); 2ndly, The separation of the trial leaf *t* upon the same principle, in consequence of the induced charge (20); 3rdly, The collapse of leaf *s* from the tendency of the opposite electricities

a and *d* to unite (16) (17); 4thly, The final attractive force resulting from these inductions.

Exp. 17. Charge both the discs *a* and *d* with the same electricity, and, whilst the leaves are divergent, present the disc *d* to the disc *a*, as before: the leaves will diverge still more energetically: at this moment the bodies appear to repel each other. Here the trial leaves, as is evident, become still more divergent, by the induction of the discs on each other, in a way precisely similar to that shown by the charge on the neutral disc in the first part of the preceding experiment. Electrical repulsion, then, as well as attraction, is preceded by a preparatory process, upon which the subsequent action depends.

Exp. 18. Charge the discs with opposite electricities, and present them to each other, as before: the trial leaves *s t* previously divergent will now tend to fall back, and will collapse considerably; the discs will then freely attract each other. The trial leaves in this experiment collapse as in the latter part of Experiment 16, by the reciprocal inductions of the discs on each other, in a direction opposite to that of the preceding experiment, the tendency of the respective electricities being to combine (16). The experiment is virtually the same in effect as Experiment 16, the only difference being, that the discs are both permanently electrified and in opposite states of electricity, instead of one of them being at first neutral, and dependent on the charged disc for its temporary electrical condition.

24. *Electrical action confined to the surface of bodies.*—It is to be further observed, as a most important and characteristic feature of electrical action, that neither induction, attraction, nor charge, have any dependence whatever on the solid contents of conducting bodies, or even on the kind of substance of which such bodies consist. Thus, whether an insulated conductor (11) be a solid mass or a thin hollow body, whether it be metallic or whether it consist of any other con-

ducting substance, the electrical charge which it is capable of receiving, and the subsequent induction or attraction which it exerts, is in each case precisely the same: the only difference is, that inferior conductors, such as wood, require in some cases a very small portion of time for the accumulation and yielding up of electricity, whilst the action of the most perfect conductors, such as metals, is as it were instantaneous.

The learned and ingenious Mr. Cavendish, whose distinguished mathematical and philosophical attainments have conferred so much honour on British science, investigated the conditions of electrically charged bodies, so long since as the year 1775, and, as appears by his manuscripts, not only anticipated by most ingenious experiments, and in a way quite astonishing—considering the then existing state of electricity—nearly all the great facts, which, in 1785 and following years, appeared in the 'Memoirs of the Royal Academy of Sciences' in France, but likewise many others of a very recent date.

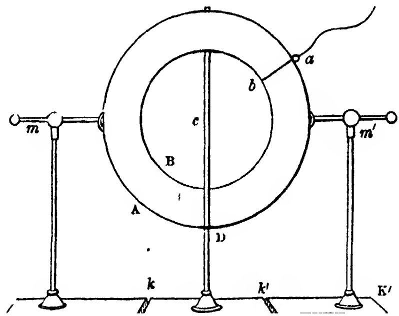
The following is Mr. Cavendish's experimental investigation of the electrical conditions of an insulated hollow globe charged with electricity, given as nearly as possible and consistent with brevity in his own words.

Exp. 19. The intention of the experiment is "to find whether, when a hollow globe is electrified, a smaller globe enclosed within it, and communicating with the outer globe by some conducting substance, is rendered at all over or undercharged, that is, positive or negative (15), and thereby to discover the law of electrical attraction and repulsion." To this effect a globe B *b*, fig. 12, of a foot in diameter, was mounted on an insulating axial rod D *c* of varnished glass, and then enveloped by two hollow hemispheres *d* A D, *d a* D, leaving a space *b a* between the interior and exterior shells of about ·4 of an inch, and constituting an external globe A *d a* D of about 13¼ inches diameter.

The two external hemispheres *d* A D, *d a* D were insulated in rectangular frames, which, by an effectual but not very

refined mechanism could be turned back, so as to expose the interior globe B *b* and leave it quite free of the two hemi-

Fig. 12.



spherical envelopes; an operation indicated in the figure through the instrumentality of the insulating supports K′ *m′* K *m* and the sliding parts K *k*, K′ *k′*. In some given point *a* of the surface, a temporary conducting communication *a b* was established between the inner and outer globes, by means of a short brass wire attached to an insulating silk thread, and by which the wire could be easily removed. Under these experimental arrangements, Mr. Cavendish communicated an electrical charge to the outer globe, in which case, as is evident, if any part of the charge tended to pervade the system as a mass, it could freely do so by means of the conducting wire *a b*. "I drew out the wire *a b*," says Mr. Cavendish, "communicating between the inner and outer globe, which, as it was drawn away by a silk line, could not discharge the electricity either of the interior globe or the exterior hemispheres; I then instantly separated the hemispheres, and applied a pair of small pith balls suspended by fine linen threads (17) to the inner globe, to see whether it was at all over or undercharged" (that is, either positive or

negative). This electroscope he further explains as being fixed at the extremity of an insulating glass rod, covered with a little tinfoil in that part intended to touch the globe. "The result was, that though the experiment was repeated several times, I could never perceive the pith balls to separate or show any signs of electricity." Every precaution appears to have been taken in this experiment, it being so contrived that, on withdrawing the hemispherical shells, their electricity became speedily discharged, so that no subsequent electrical action could possibly arise.

Mr. Cavendish further endeavours to discover how small a quantity of electricity, not sensible to his electroscope in its ordinary state, might be made apparent; for which purpose he communicated to the balls (fig. 7) a weak positive or negative electricity: in this way he finds that he could render sensible a quantity of redundant electricity on the inner globe, less than the $\frac{1}{60}$th of that lodged on the outer; and hence concludes, that in his original experiment the redundant electricity, if any existed on the interior globe, must "certainly have been less than the $\frac{1}{60}$th of that on the outer globe," but he thinks "there is no reason to believe that the inner globe was at all charged with electricity."

Although this simple and perfectly conclusive experiment by Mr. Cavendish fully proves the tendency of electricity to the surface of common matter, yet the following, which may be taken as the converse of Mr. Cavendish's process, is by no means unimportant.

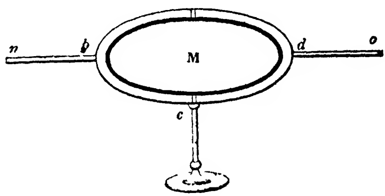
Exp. 20. Charge the interior globe B *b*, fig. 12, either positively or negatively, the hemispherical envelopes being drawn back, and the communicating wire *a b* removed: when so charged, replace the hemispheres about the interior charged globe, as shown in the figure, attach the communicating wire *a b* to a slight rod of varnished glass, by means of a cement of sealing-wax, and insert it, as before, so as to make a temporary communication between the interior and the outer

spheres; withdraw the wire and turn back the hemispheres; all the electricity will have left the inner and previously charged globe, and be found resident on the exterior hemi-spherical shells, which will be found to affect the electrosope (17) from the instant a conducting communication has been established between the inner and outer shells.

These last experiments may be effectually carried out with a small sphere of 2 inches diameter, and hemispherical shells of light copper sheet; the whole constituting an elegant piece of electrical apparatus.

25. An experiment somewhat similar to that of Mr. Cavendish has been described by M. Biot in his fine work 'Traité de Physique,' which if the student should fail to verify, he must not be disappointed. In this experiment an insulated conductor of a spheroidal form M, fig. 13, has closely fitted to its surface two similar spheroidal envelops *abc*, *adc*, furnished with insulating handles *b n*, *d o*, and without leaving any sensible space between. These shells being removed, the interior body M is charged with electricity; after which the envelops are replaced, as shown in the figure; on being again withdrawn, all the charge it is said will have passed into the superficial shells, and the interior body M will be found perfectly neutral. Now it is quite clear that this experiment cannot possibly succeed, unless the envelops be rapidly and simultaneously withdrawn; so rapidly, as to exceed the rapidity of the electrical expansion over any small space or opening upon the surface of the interior body M, which will necessarily occur between the envelops at the instant of their separation, and so simultaneously that one shall not be in any sensible degree after the other; for if it be, the charge will certainly expand

Fig. 13.



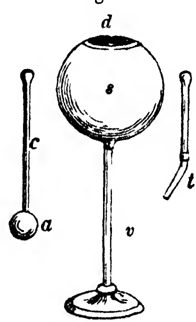
from the remaining envelop over the exposed part of the interior spheroid. This experiment, therefore, is much more precarious and inconclusive, and certainly far inferior to that of Mr. Cavendish.

The experiment first proposed by the distinguished French philosopher Coulomb consisted in sinking several holes of about $\frac{1}{2}$ an inch in diameter in a solid conducting body, and then, having insulated and electrified this body, he introduced into the interior of these holes a small conducting disc of gilt paper fixed to the extremity of a thread of gum lac; this disc being again withdrawn did not exhibit any electrical manifestation; he concludes therefore that the charge cannot pervade the substance of the body. The experiment, although true in its result, is still not perfectly conclusive, inasmuch as the disc may not, when passed into the interior, be susceptible of the previous inductive action requisite to its becoming charged with electricity: we know that such is the case in the interior of charged glass, in which an abundant charge exists, and yet an insulated disc placed within it will not become electrified.

26. Of this class of experiment the following may be regarded as an instructive and important example.

Exp. 21. Let *s* be a thin hollow metallic sphere about 4 inches in diameter, and having a circular opening at *d*, about an inch and a half across. Place this sphere on a long insulating support *v*. Let *a* be a small ball of brass about $\frac{3}{4}$ths of an inch in diameter, either solid or hollow, and insulated on a slender rod of glass *c*. Charge the small sphere *a* with electricity so as to render it powerfully attractive and repellent of an insulated trial leaf electroscope *t*, and afterwards plunge it within the interior of the shell *s*, but without touching the edge of the

Fig. 14.



opening at *d*. Having brought this electrified ball in contact with the interior of the shell, withdraw it again by its insulating handle carefully, in a similar way. It will be found that every particle of the charge will have left the small sphere *a* to appear on the outer surface of the sphere *s*, which will have now become attractive and repellent of the trial leaf *t*: by a few repetitions of contact of the inner surface of *s* and the small sphere *a*, after being charged, the exterior charge upon *s* may be rendered very powerful; for notwithstanding the previous communication of electricity to *s*, the small sphere *a* will be continually and completely robbed of its charge by contact with the interior of the shell. If the hollow shell *s* be originally charged, and the small insulated ball *a* in a neutral state be introduced within it, then, as in the experiment by Coulomb, it will not on removal exhibit any electrical sign.

27. The most general and perhaps the finest experiment of this kind was that by Faraday, carried out in the lecture-room of the Royal Institution, in London, in Nov. 1837. Having constructed a light chamber of 12 feet cube covered with metallic leaf, and insulated by adequate supports, he placed himself within it, used lighted candles, very delicate electroscopes, and other tests of electricity; but although the cube was placed in communication with a powerful electrical machine, and charged so highly as to throw off powerful sparks and brushes of light from the exterior surface, yet not the least effect was produced upon the electroscopes and other bodies within.*

28. *Other sources of electrical excitation.*—We have as yet considered ordinary electrical excitation as arising exclusively from friction; it will, however, be requisite to understand, as before remarked (2), that although friction under some form is for common purposes the most available source of this peculiar state of certain bodies, yet it is not the only source: a

* Electrical Researches, p. 366 (1074).

great variety of operations, both natural and artificial, are also causes of electrical disturbance; such, for example, as pressure, simple contact, and other mechanical processes,—changes of temperature,—changes of form,—chemical changes,—magnetic influence, and some others. The following are interesting illustrations.

Exp. 22. *Excitation by chemical change of form and temperature.*—Liquefy a little common brimstone by a gentle heat over a fire, in a covered earthenware vessel, and pour it into a dry wine-glass; put a short rod of glass into the liquid, to serve as an insulating handle: when cold, remove the solid brimstone cone from the glass, and it will be found, by means of the trial leaf, to be in a state of active excitation, together with the glass, which will be in an opposite or positive state. Chocolate and several substances become electrically excited in this way in passing from a fluid to a solid state; and the evaporation of pure water from a clean platinum crucible made red-hot is unquestionably attended by an electrical development.

M. Pouillet, however, failed to verify this, and contends, with some reason and much ability, that all changes of this kind produce electricity by the attendant chemical action. Thus, in the evaporation from the earth's surface, pure water becomes separated from its various saline impregnations. Now, it is undoubtedly true that the electrical indications from artificial evaporation are less from pure water than from saline solutions, and are always increased by the presence of chemical action; still the author of this work, by means of a very delicate manipulation, obtained electrical manifestations in the evaporation of pure water from a clean and heated surface of platinum, in which there was no fair ground for assuming the existence of chemical action.

Exp. 23. *Excitation from changes of temperature only.*—Expose a piece of tourmaline to a moderate heat, by placing it on a common watch-glass carefully held over a spirit lamp for a short time. This curious stone, in cooling, will exhibit a

strong electrical action, just as if it had been excited by friction. Several crystallized gems become electrical in this way.

Exp. 24. *Excitation by chemical action.*—Pour some dilute sulphuric acid upon coarse iron filings contained in a green glass bottle, and place the bottle on a small insulated stand; then during the chemical action which ensues, the exterior surface of the bottle will appear electrified, and will attract the trial leaf when presented to it, or cause the electroscope (17) to diverge.

Exp. 25. *Excitation by contact only.*—Let two circular discs, one of zinc and the other of copper, about 5 or 6 inches in diameter, be well polished and faced up together, and be mounted on insulating handles. Apply the faces to each other, and then separate them again: one of the discs will give positive, the other negative electricity.

The charge in this experiment is so extremely small as only to be made sensible through the medium of the most delicate instruments, to be hereafter described. It has been contended by our most celebrated chemists, that this weak charge is not the result of pure contact, but arises from an insensible but slight oxidation of the zinc surface from the moisture and oxygen of the air. Volta, however, with whom the experiment originated, as also many distinguished philosophers of the present day, consider that the mere contact of the dissimilar metals is the source of electrical change. The question is an important theoretical question, and still open to much investigation.

Exp. 26. *Excitation by contact with pressure.*—Lay a piece of white silk ribbon, about 6 inches in length and 2½ inches wide, on a clean block of wood having an insulating handle. Place a similar piece of black ribbon immediately over it; cover this by a second block, and subject the whole to severe pressure by means of a common press. Withdraw the blocks and silk, and whilst sustaining the mass by the insulator, remove the upper block and separate the pieces of silk. Each

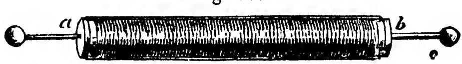
piece will have received a slight charge, sensible to a moderately delicate electroscope.

Some exceptions have been taken also to this class of experiments, on the ground that it is impossible to apply pressure without friction, and that in the mere separation of the silk friction must necessarily ensue. Allowing, however, for all this, there is sufficient evidence for concluding that bodies pressed closely and powerfully together exhibit on separation electrical signs. Thus, among natural substances, we find the separation of the laminæ of mica, or Muscovy talc, attended by powerful electrical signs, and not unfrequently by the presence of electrical light.

The ingenious De Luc, adopting the contact theory, arrived at a sort of spontaneous perpetual electrical excitement, which he termed the Electric Column, and which is constructed in the following way:

Prepare a series of about a thousand or more small circular discs of silver, zinc, and paper; place them in a glass tube previously well dried, taking care that the discs are all placed in the same order, as *silver—paper—zinc—silver—paper—zinc*, and so on. Secure the extremities of the tube with corks or metallic caps, and let short wires pass through them, so as to press upon the terminating plates of the series, as in the annexed figure 15. Then by the contact and association of these bodies in consecutive groups, each extremity *a*, *b*, of this

Fig. 15.

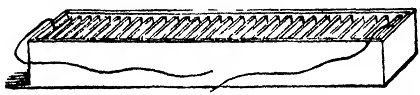


dry pile, as it is called, will evince opposite electrical states; the zinc extremity being positive, and the silver extremity negative. A pile of this kind is extremely useful in affording at all times weak positive or negative electricity.

Excitation by the contact of metals and fluids.—Another powerful and peculiar source of electrical excitation consists in a similar arrangement of metals with water or moistened cloth interposed, commonly termed the *voltaic pile.* Copper and

zinc are the metals usually employed. If a series of about 50 circular or square discs of these metals, of about an inch in diameter, be grouped in the order of *zinc—moistened cloth—copper*, both the zinc and copper extremity will exhibit attractive and repellent effects, such as have been already described (16). The metallic plates, when square, may be joined at their faces, and placed so as to form a series of cells in a trough of wood, as in fig. 16. In this arrangement, if river water

Fig. 16.



be poured into the cells, the electrical power of the terminating plates is considerable; the zinc extremity being electrified positively, and the copper negatively; and if the interposed fluid be a solution of common salt in water, a faint shock will be experienced on touching the opposite extremities of the series.

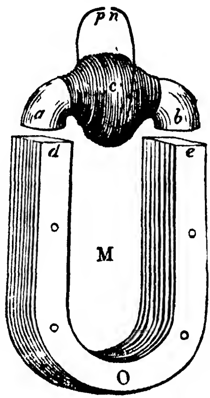
Excitation by living animal matter.—Certain fish, such as the torpedo and gymnotus, have a similar electrical power, derived from a peculiar organ acted on by a fluid, and which enables them at will to excite a peculiar and very strong electrical action.

Excitation by magnetic influence.—A peculiar species of electrical excitation may be caused by the influence of magnetism on metallic wires, exerted either by the natural magnet termed the loadstone, or by a combination of steel bars, forming a compound artificial magnet.

Exp. 27. Coil some hundred feet of copper wire, covered with silk, carefully round a soft iron bar, allowing the extremities of the bar to project freely beyond the coil. Fix the ends of the coil extremely near each other, and bring the ends of the bar into contact with the poles of a very powerful magnet. A sort of electrical disturbance will ensue throughout the whole extent of the wire, which may be made to manifest itself in the form of a spark between the ends of the coil, and

to exhibit other electrical indications; and this effect will be produced whenever we break or make contact with the magnet. Let M, fig. 17, be a battery of bent magnetic bars; *a b*, a curved bar of soft iron having from 300 to 500 feet of copper wire coiled round it at *c*, the extremities of which, *p n*, come very near each other. Then, when a contact is made between the projecting ends *a b* of the bar of soft iron and the ends or poles *d e* of the magnet M, electrical indications will ensue between *p* and *n*. To facilitate the effect, one extremity of the coil is plunged into a small cup filled with mercury, and the opposite end is made to close as it were upon the surface, so as to be very near it: this arrangement, however, is not shown in the figure.

Fig. 17.



We are indebted to the admirable researches of Dr. Faraday for this beautiful fact.

With an arrangement of this kind, and with a coil of about 3000 feet of wire, M. Pixii, of Paris, obtained ordinary electrical attractions and repulsions on leaf gold. In this case the magnet M was made to revolve rapidly on a strong central axis passing through O M, the poles or extremities *d e* being extremely near the ends *a b* of the curved bar of soft iron carrying the coil, so as to produce an insensible contact, every time the poles passed the ends of the bar; the result was a continued current of most brilliant sparks between the extremities *p n* of the coil. Similar results were subsequently obtained by Mr. Saxton, who, by a most ingenious mechanical arrangement, caused the iron *a c b* and coil *c* to revolve instead of the magnet.

29. *Electrical Manipulation.*—A few remarks on the elec-

trical manipulation requisite to the success of the several experiments we have hitherto described, may not be here altogether out of place. It may, however, be observed that these experiments have been purposely selected as being of the most simple and easy kind.

In the first place we have to remember, that since water is found in the class of conductors (9), and that the success of electrical experiments mainly depends on good insulation, it is most important to select a dry atmosphere for such experiments; or otherwise to render the air dry artificially by an Arnott's stove, which is admirably adapted to this purpose. It will be further desirable in certain cases to perfect the insulations by exposing them to the warmth of a small iron, heated to redness, and curved in such way as nearly to encircle the insulating support, as represented in the annexed fig. 18. Moreover, the surfaces of glass rods used as insulators should be carefully varnished over with a solution of shell lac in rectified spirit, laid on the glass before a fire, the glass having been previously warmed. If these precautions be not taken, the accumulated electricity will speedily disappear by conduction over the surface of the insulators (8). Silk threads intended for insulation should be treated in the same way.

Fig. 18.

The principal articles requisite to the student for the prosecution of early experimental inquiries are the following: A few tubes of glass, varying from $\frac{1}{2}$ to $1\frac{1}{2}$ inch in diameter; some glass rods from $\frac{1}{5}$th to $\frac{1}{2}$ an inch in diameter; a few filaments or stout threads of glass, of about the $\frac{1}{20}$th to the $\frac{1}{10}$th of an inch in diameter; silk thread of various sizes; fine threads of unspun silk from the silk-worm, for the suspension of light bodies; shell lac, common sealing-wax, a roll or two of brimstone, and one or two other electrics of the resinous class (5); a little soft white silk, coarse oiled silk, fine leather, and some dry woollen stuff and dry hare-skin, for excitation; a piece of aurum musivum; straw reed of

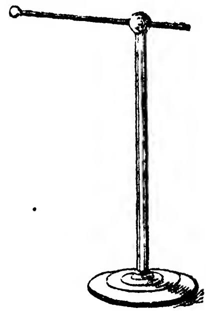
various diameters; light cotton and linen thread; a few small balls of wood and cork of various sizes, from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in diameter; some small balls formed of the pith of elder, varying from the $\frac{1}{20}$th to the $\frac{1}{3}$rd of an inch in diameter, and which are easily produced by turning the pith about in small hemispherical cavities formed in any soft body capable of attrition, such as soft sand-stone; sundry other light bodies, such as cotton wool, downy feathers, &c.; a few books of Dutch metal and gold and silver leaf; metallic rods of various sizes,—brass wire answers very well; a few hollow metallic balls,—these are usually made of brass, and polished; a solution of shell lac in spirits of wine.

Electrical excitation is greatly promoted by the use of an amalgam of zinc, tin, and mercury, in the proportion of 1 part tin, 2 parts zinc, and 4 parts mercury. The zinc should be first exposed to a melting heat in an iron ladle; the tin is then to be added, and finally the mercury: this being gently heated in another small iron ladle, should be poured gradually upon the liquefied metals, stirring the mixture carefully at the same time. After allowing the amalgam to cool down, it should be poured, just before solidifying, into a wooden or iron box, and be constantly agitated by shaking until cold. It will commonly be found in the form of a powder, or an easily pulverized mass. The mass should be triturated in an iron mortar, and sifted through a small muslin sieve, so as to obtain an extremely fine powder: this powder, when employed to promote excitation, should be rubbed up in a mortar with a little lard, just enough to hold the particles together, and be then spread on the rubber with a common palate knife. It is principally employed for the excitation of glass, which may be powerfully excited by this amalgam, applied to the rough side of oiled silk or basil leather.

An insulating stand for the suspension of light bodies will be found very convenient to the student; also one or two insulating tables. The former is easily obtained by running a slender rod of glass through a ball of wood or cork, and

fixing the ball on an extremity of a slender glass rod, as represented in the annexed fig. 19. A horizontal arm of this kind may be well employed for suspending a trial leaf, fig. 4, page 10. Wine-glasses with long stems, made dry and varnished, are convenient, when inverted, as small insulating tables: a common watch-glass, cemented by sealing-wax at the extremity of a long slender rod of glass, fixed on a firm base, is a very effective insulation. An insulating stool supported on four stout and well-varnished glass pillars, and upon which a person may conveniently stand or sit, is also a requisite piece of electrical apparatus. It may consist of a piece of well-seasoned mahogany about 14 inches wide and 20 inches in length.

Fig. 19.



30. In conclusion it may be observed, that in all cases of excitation it is desirable to preserve the surface opposite to the excited surface in a perfectly dry state, and protected from moisture: thus plates of glass will excite more freely on one surface when the opposite surface is varnished with shell lac, or what is better, coated over with sealing-wax. The electrical tube or ball described in Exp. 4 (7), being extremely available to the purpose of the student, should be thus treated: the interior surface should be either varnished or coated with sealing-wax;—this is effectually done by first pulverizing the sealing-wax, and then placing it within the tube; after which apply a strong heat sufficient to dissolve the wax, and allow it to float over the surface of the glass. A tube thus prepared with the amalgam just described (29) will never fail, when dry, to evolve positive electricity in great quantity; and, when coated on the outside with sealing-wax or a thick coating of shell lac varnish, negative electricity also, as before observed (15), may be procured. In this case, however, the surface must be excited with woollen, or soft white silk, or hare-skin.

II.

Prevailing Theories of Electricity—Views of Du Fay and Symmer—The Franklinian Hypothesis—Views of Æpinus and Cavendish—Eales's Hypothesis—Views of Faraday—Grove's correlation of Physical Forces.

31. Having now considered and illustrated by simple experiments some of the more obvious and elementary phenomena of ordinary electricity, those which first demand attention, and upon the clear apprehension of which all further progress in this department of science mainly depends, we may now briefly advert to the prevailing theories, or rather philosophical speculations, which have been advanced in explanation of them.

If we examine the notions entertained by some of the more early Electricians, we find them to be, in many instances, of a somewhat rude and unsatisfactory character. Boyle imagined that an electric emitted a sort of glutinous effluvium which laid hold of small bodies and brought them back to the excited electric. The celebrated Newton, however, in two Queries at the end of his 'Optics,' appears to imagine, with his accustomed diffidence, that electric bodies, when excited, emit a very attenuated elastic fluid or exhalation, in consequence of the vibratory motion of their parts.

That electrical phenomena depend on some infinitely subtle and powerful agency pervading the material world, is in the present state of natural knowledge very probable. That this agency is either in itself a subtle form of matter, or a force originating in some all-pervading material element, differing essentially from any kind of matter of which we have the least cognizance, is also highly probable, although by no means certain. Admitting, however, these suppositions, two theories claim our especial attention.

32. The first originated in the discoveries of Du Fay and Symmer (14). This theory supposes electricity to be an infinitely

attenuated fluid pervading the most compact bodies, being compounded of two primary elements possessing distinct and opposite properties. These elements, which are called *vitreous* and *resinous* electricities, are also assumed to be highly elastic fluids of perfect fluidity and elasticity, each repulsive of its own particles, but attractive of the particles of the other; so that when combined, they completely condense or neutralize each other, and electrical repose or quiescence is the result. When, however, a disunion of these elements takes place, each becomes active, and hence the source of the phenomena of electrical excitation, which consists in a separation and abstraction of one of the elements, leaving the other in excess or uncompensated. The direct consequence of this is that the elementary electricity in excess, whichever it be, will tend to disturb the neutral electricity of any substance near it by operating upon the opposite elementary electricity it contains; so that the balance of the two electricities in combination in the neutral body is overset, its electricity being separated, as it were, into its constituent elements. This constitutes *induction* (20). Now *attraction* is an immediate consequence of this induction, since the opposite electricities tend to unite, so that the bodies, if free to move, approach each other (23). When the opposite electricities are already in excess in two substances, they attract, and the bodies tend towards each other as before. *Repulsion* is supposed to arise from the excess of either of the elements in both the repellent bodies, the particles of which, by the hypothesis, repel each other.

This theory does not recognize any peculiar affinity or attractive force between either of the electricities and common matter: it assumes, however, that there is an intimate association of the quiescent or compound element termed *electricity* with the particles of common matter, and that this electricity is indefinitely attenuated and imponderable. When resolved into its constituent elements, and a portion of one of them is abstracted, then the element in excess is found by the repulsion

of its particles in a thin stratum on the surface of the body where it is retained, within a hollow vase of air, by the pressure of the atmosphere.

33. The second view of electrical action, differing essentially from the former, originated at the same time with Dr. Franklin in America, and with Dr. Watson in England, about the year 1747. It has been with justice called more especially the *Franklinian Hypothesis*, from the beautiful and extensive researches of that celebrated Philosopher, and the admirable way in which he brought them to bear on the general phenomena of electricity. This theory supposes the existence of a single elementary homogeneous fluid of extreme tenuity and elasticity, without weight, existing in a state of equable distribution throughout the material world; it is assumed to be repulsive of its own particles, but attractive of all other matter. When distributed in bodies in quantities proportionate to their capacities or attraction for it, such bodies are said to be in their natural state. There is in this case a sort of equilibrium of distribution, and the result is electrical repose. When, however, we increase or diminish the quantity in any substance, we disturb this equilibrium, and a powerful action ensues, arising out of the attractive force of the body to regain its natural share of the electric fluid, if its original quantity be diminished, or to throw it off upon other bodies, if increased.

According to this theory, *excitation* is the result of a change in the relative attractive forces of the rubber and electric for electricity, when brought into contact; in which case the attraction of the one for electricity is increased, and that of the other diminished. Still, however, whilst in contact, the equilibrium of repose is not apparently disturbed (6), since the two substances may be taken as one: when, however, we disunite them, the original attractions are restored whilst the new distribution remains, and the result is, that one of the bodies becomes overcharged with the quantity abstracted from the other, which is consequently minus or undercharged;

that is to say, one is charged *positively*, the other *negatively* (6).

Electrical Induction is the result of the tendency of the electric fluid to an equilibrium of distribution. If a body be overcharged, it endeavours to throw off the superabundant quantity upon any other body near it, causing the electricity of the neutral body to recede to its more distant parts, so as to make, as it were room for it. (20) (21.) If undercharged, or deficient of its natural share, then the common matter of the body attracts towards it the electric fluid in any other neutral body near it, causing a flow, as it were, of the natural electricity of the neutral body from its more distant parts; in either case disturbing the electrical distribution of the neutral body, and electrifying its opposite extremities,—the one positively, the other negatively (21).

Attraction is an immediate consequence of this influence of induction, from the tendency of the opposite, or plus and minus states, to unite and equalize the distribution; the attractive force of the matter of one of the opposed surfaces for electricity being increased, the other diminished. In fact, the one is in a condition to supply the electricity required by the other.

Electrical Repulsion is the result of the repulsion of the particles of electricity collected in the repelling bodies when these are overcharged, and the result of the attraction of the denser fluid in the medium surrounding the body when undercharged.

34. Both these theories, or rather hypotheses, explain readily many complicated phenomena of electricity, yet they must be admitted to be extremely defective in their general application to the mass of facts which they are required to elucidate: one of the great difficulties in the way of both, is the phenomenon of electrical divergence (13), since it may be shown, that if assumed to depend on a purely repulsive force existing in the molecules of an electric fluid, then it is a species of repulsion essentially different from any repulsive agency of which we

have the least experience,—its action being at great distances, and operating between distinct and circumscribed collections of repulsive matter disposed on the surfaces of bodies. But it may be shown on common mechanical principles, that no motion could possibly take place in this way. Some of the French philosophers, aware of this fact, have accordingly endeavoured to account for electrical divergence by a mechanical action on the surrounding air. The Franklinians, on the other hand, when they found it impossible to apply their principles to the divergence of *negatively* electrified bodies, that is to say, bodies from which the agency has been abstracted but upon which the repulsion is assumed to depend, resorted first to an attraction in the surrounding medium as the cause of the separation of such bodies. Many were in consequence led to explain every case of electrical divergence on this principle, and to deny the existence of a repulsive force in electricity altogether. As it became, however, difficult to support this view, they were finally led to assume that the repulsion in such cases arose from an actual repulsive force between the particles of common matter when deprived of their natural share of electricity; all of which, it must be allowed, are only so many plausible excuses for a defective theory.

These difficulties have been still further increased from the circumstance that very perfectly insulated bodies have by modern experiments been found capable of retaining their charge in an extremely rarefied medium, such as that produced by the most perfect air pumps, and that electrical divergence and attraction can be exhibited in such a medium, much in the same way as in a dense atmosphere.

35. Æpinus and Cavendish were among the first to discover and supply the defect in what was termed the Franklinian Theory, by attributing a repulsive force to the particles of common matter when deprived of their electricity. Mr. Cavendish, in the Philosophical Transactions for 1771, lays down his hypothesis in the following way, which, although quite original with him, in no sense differs from that of Æpinus.

"There is a substance which I call the electric fluid, the particles of which repel each other and attract the particles of common matter with a force inversely at some less power of the distance than the cube: the particles of all other matter also repel each other, and attract those of the electric fluid according to a similar law."

All bodies in their natural state contain such a quantity of electric fluid, interspersed between their particles, that the attraction of the electric fluid in any one point for a given particle of matter shall be equal to the repulsion of the matter on the same particle. In this state Mr. Cavendish considers the body as saturated with electricity. If the body contains more, he calls it overcharged,—if less, undercharged. This is the hypothesis, and upon which he bases a learned and most valuable mathematical investigation.

36. In his subsequent manuscripts, however, Mr. Cavendish appears disposed to revise this hypothesis, as we find in a Paper termed 'Thoughts concerning Electricity,' and which is of a very interesting character, he says, "Electricity seems to be owing to a certain elastic fluid interspersed between the particles of bodies; and perhaps also surrounding the bodies in the form of an atmosphere: if it thus surrounds the bodies it can only extend to an imperceptible distance, that is, to a distance much less than that of the smallest distance within which two bodies can be made to approach; the attractive and repulsive forces, however, extend to very considerable distances. That the electric atmospheres cannot extend far, is, I think, evident from the fact that the electric fluid will not pass from one conductor to another, however near they be, except by jumping as it were in the form of sparks; whereas, if the electric atmospheres intermixed, it should seem as if the electricity might flow quietly from one to the other. Let any number of bodies which freely conduct electricity be connected by conducting rods, the electric fluid will be evidently equally compressed in all these bodies; for if not, the fluid would move from the bodies in which it was most

compressed to those in which the compression was less, until the compression was equal: but yet it is possible that some of these bodies may be made to contain more than their natural quantity of electricity, and others less. To make what is here said more intelligible, let us suppose a long tube to be filled with air, and let a given part of this tube, and consequently the air within, be heated, the air will thereby expand, and hence that part of the tube will contain less air than it did before, but yet the air in that part will be just as much compressed as in the rest of the tube: in like manner, if you suppose the electric fluid to be not only confined within bodies, but also to surround them; then if any power be applied to prevent its extension from them, such bodies may be made to contain less electricity than they would otherwise do, but yet the electric fluid surrounding them will be just as much compressed as it would be if that power were not applied.—It will surely be needless to warn the reader not to confound compression and condensation." Mr. Cavendish then proceeds to his hypothesis, and gives the following definitions and hypotheses:—

"*Def.* 1. When the electric fluid within any body is more compressed than in its natural state, I call that body positively electrified; when it is less, I call the body negatively electrified.

"*Def.* 2. When any body contains more of the electric fluid than it does in its natural state, I call it *overcharged;* when less, I call it *undercharged.*

"*Hyp.* 1. Every body overcharged repels an overcharged body and attracts an undercharged body.

"*Hyp.* 2. Every undercharged body attracts an overcharged body and repels an undercharged body.

"*Hyp.* 3. When an overcharged body is brought near another body, it makes it less able to contain electricity than before.

"*Hyp.* 4. When an undercharged body is brought near another, it makes it more able to contain electricity."

Upon these principles Mr. Cavendish, with the aid of certain corollaries, proceeds to explain the phenomena of electricity.

In some additional notes he considers the case of a fluid "whose particles mutually repulse each other" and uniformly spread through infinite space," and says, if the repulsion be inversely as the nth power of the distance, n being greater than 3, it would constitute an elastic fluid like air, "except that the elasticity would be as the $n + 2$ power of the distance of the particles inversely, or as the $\frac{n+2}{3}$ power of the density directly."

37. Eales, an intelligent Irish gentleman, who wrote on the subject of electricity about this period, viz. 1771, advances an hypothesis, which, upon the whole, may be probably found less embarrassed than either of the preceding. Mr. Eales assumes, in common with other philosophers, the existence of an extremely subtle agency, termed *electricity* or the *electric fluid*, and, as appears by his letters to the Royal Society in 1757 and 1758, he was one of the first to discover the two elementary electricities of which the electric fluid is said to be composed. These two electricities, or electrical powers, as he terms them, consist of two distinct elastic media, which equally condense and attract each other, and are at the same time equally attracted by all other matter: they are supposed to be repulsive of their own particles, and to have each, when separated from the other, a power of expansion in all directions, the limit being determined by the attractive force of the matter of the electrified substance acting against the electrical force of expansion. In this way an electrical stratum is conceived to exist about any substance charged with electricity, held to its surface by the attractive force of the matter of which the substance consists. Excitation, as in the first theory, consists in a separation and abstraction of one of these elementary forces, leaving the other in excess. *Induction* is the result of the expansion of the electricity in excess towards any neutral body,—attracting the one element,

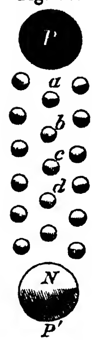
but repelling the other element of the electricity of the neutral body, and so disturbing its electrical state (21). Attraction is the consequence of this by the combination of the opposed electricities (23), which condense each other at a distance, and so drag the bodies together as it were through the medium of their respective electrical strata held by attraction to their surfaces. A similar attractive effect results from the expansions of the electricities of two substances oppositely electrified (23). If the two electrified expansions be similar, as in the case of similarly charged bodies, then the meeting of these at the point of contact will cause the bodies to separate up to a distance at which the repulsive action of the elementary electrical particles is balanced by the attractive force of the matter of the bodies for these particles (23).

Such were the views of Mr. Eales; and it must be allowed that they involve less difficulty than either of the others. That two opposite electrical forces or powers are called into play in every case of electrical action, is quite certain, from whatever source they may be conceived to be derived; and it is hence only required to explain how these forces act in bringing about the perceived effects. Mr. Eales had certainly the merit of originating a doctrine of opposite electrical forces; but being a prolix, and in some respects a rather unmethodical writer, his views have not met with that attention which they really merit.

38. Within the last 25 years a bright light has been thrown on the probable nature and laws of electrical action, through the magnificent researches of Faraday. This justly celebrated philosopher, recognizing two kinds of electrical force, conceives electrical induction to depend on a peculiar form of physical action, propagated between contiguous molecules of force. In these intermediate molecules a separation of the opposite electricities takes place, and they become disposed in an alternate series or succession of positive and negative points or poles: this he terms a polarization of the particles, and in this way the force is transferred to a distance.

Thus, if in fig. 20, P represent a positively charged body, and *a b c d* intermediate molecules, then the action of P is transferred to a distant body N by the separation and electrical polarization of these molecules, indicated by the series of black and white hemispheres. Now if the particles can maintain this state, then insulation obtains; but if the forces communicate or discharge one into the other, then we have an equalization or combination of the respective and opposite electricities throughout the whole series, including P and N.

Fig. 20.



39. Although in the above fig. 20 we have resorted to the exhibition of gross material particles by way of illustration, yet the theory is not dependent on the actual existence of such particles, as usually assumed in the chemical doctrine of material atoms; rather on the contrary, it contemplates something much more refined. This theory is in fact limited to the laws and arrangement of powers or forces, either as existing through space or through common matter, without at all considering indefinitely small atoms of mere solidity having certain powers impressed on them. Faraday does not stop to associate together by incomprehensible mechanical relations an hypothetical electric fluid, with gross matter such as this, but comes at once to a positively existing state of things. If we are to have assumptions in this branch of physics, which it appears we must, then he conceives that we should assume as little as possible. Now it is safer and more simple to assume the existence of molecules, or atoms, taken only as mere centres of force, than the existence of little impenetrable nuclei of solidity with superadded powers. In the latter case, if we take such atoms as indefinitely small, they at last vanish into mere mathematical points, and become as so many nothings; still the forces grouped around them are left, and in this way we conceive only of material atoms, as so many centres of force,—and which force may be further conceived

to pervade all space, and penetrate every thing we call substance. In fact, we find nothing in space, either vacant or occupied by common matter, but forces of various kinds, and the lines in which they are exerted. The student, it is true, may find it difficult to bend his mind to the conception of mere forces or powers, independent of a something separate from these forces, and which we call matter; yet he must remember, that in this branch of science it is really with powers or forces only that we are concerned, and that it is far more difficult after all to imagine matter without powers or properties of force, than the forces without the matter. We recognize the forces almost everywhere (1), but we recognize the ultimate atom of mere solidity nowhere, except in the imagination.

Considering then what we call an atom of matter as an atom of force, matter will be continuous and devoid of space within; for the grouping together of such atoms into a mass will give that mass every property, as regards force, which we observe masses to possess; and nothing can be supposed of the disposition of force in or about an indefinitely small solid nucleus, that cannot be equally well referred to a centre of mere force without the solid nucleus: it is hence competent to us to reason upon such forces and centres of force, just as we should of solid atoms and the forces superadded to them. In the way of hypothesis, as regards forces, the solid nucleus is of no use to us whatever—supposing the material forces to be compressible or extensible, that is, to possess the quality of elasticity—then we have no difficulty in conceiving the increase or decrease of matter in bulk; nor shall we have any difficulty in conceiving the propagation of that species of electrical action which we call *conduction*, or the arrest of it, which we call *insulation*, without having an intervening nonentity space to jump over; which is a sort of negation of all properties whatever, so that in the new views which Faraday has advanced relative to electrical action, he has very wisely disencumbered his mind of the presence of what may be termed solid material atoms, and recognized only certain forces and laws of force,

which are as well known to us as the force of gravity and lines of gravitating force. In this sense we have lines of electric force, of inductive force, of magnetic force, and so on.

If intervening particles of common matter, taken as centres of force, be present, they may, and probably do, take part in carrying on the line; but if not, the line extends through space. Such lines of force, either straight or curved, being conceived to unite centres of force and masses together, then certain affections of these lines, as vibrations either lateral or oblique, or any other kind of affection, may give rise to a great variety of new phenomena.

This theory then being limited to mere powers or forces, and the laws of their arrangement, considers particles of common matter taken as centres of force, as being more or less conducting; the particles not being in their quiescent state arranged in a polarized form (fig. 20), they become so by the influence of contiguous and charged particles,—they then assume a forced state, and tend to return by a powerful tension to their original normal position;—being more or less conductors, the particles charge either bodily or by polarity;—contiguous particles can communicate their forces more or less readily one to the other: when *less* readily, the polarized state rises higher, and *insulation* is the result; when more readily, *conduction* is the consequence. Hence conductors and insulators are bodies whose particles have naturally more or less power to communicate the electrical forces, just as they possess other natural properties. *Induction* is the action of a charged body upon insulating matter, or matter the particles of which communicate the electrical forces to each other in an extremely minute degree. Such are the theoretical views and results of Faraday's investigations; and it must be allowed that he has placed them, by a most conclusive sequence of experiments, carried out with admirable skill and profound reasoning, far within the limits of mere conjecture.

40. Grove, in a very elegant and able Memoir on the 'Correlation of Physical Forces,' considers all those peculiar

powers which we term electricity, magnetism, heat, light, &c., as correlative, and as having a reciprocal dependence on each other, through the agency of motion, into some form or mode of which they may be resolved. Thus the gross and palpable motion which is arrested by the contact of one body with another, may be resolved into molecular vibration, undulations, &c., and which vibrations or undulations constitute heat or electricity as the case may be,—a view supported by an authority no less than that of the great Lord Bacon, who, from a large induction of facts, concluded that heat is essentially motion.

The student, however, will do well to remember, both for his own sake and for the sake of others, that all these speculations are mere assumptions, that what we call a theory or hypothesis is a sort of artificial representation to the mind of a possible way in which observed phenomena may be linked as it were into a consecutive chain,—but of the actual truth of which we can assert nothing: we must hence be very careful not to substitute the assumption for the fact, and yield to the temptation, so strongly fostered by habit, to refer observed phenomena to certain recognized views, to which the mind may have been long moulded and shaped.

III.

Electroscopes—Condenser—Electrical Machines—Hydro-electric Machine—Electrophorus—Theoretical views of the action of Electrical Machines—The Electrical Jar or Leyden Phial—Theoretical views of the Electric Jar—Electric Batteries—Electrometers—Quadrant Electrometers—Torsion Electrometer—The Bifilar Balance—The Scale-beam Electrometer—The Discharging Electrometer—The Unit Measure—The Quantity Jar—The Thermo-Electrometer.

41. Instruments for indicating the presence and quality or kind of electricity are termed *Electroscopes* and *Condensers.*—Electroscopes consist of any delicately suspended light body, capable of yielding to the smallest degree of force. Downy feathers, reeds, small balls of the pith of elder, fragments of cotton wool, &c., when suspended by fine filaments of silk or cotton from any convenient support, such as that shown in fig. 19, constitute the readiest and most simple form of this instrument. The metallic leaf already described (13), attached to a slip of paper and suspended in any convenient way, is perhaps the best electroscope of this form: when constructed of leaf gold or silver, and shielded by plates of glass, it is sensible to the least possible force. Of the more elaborate kinds of electroscope, the following are worthy of attention.

The Balanced Needle.—This form of electroscope may be advantageously constructed as follows: upon a short bent

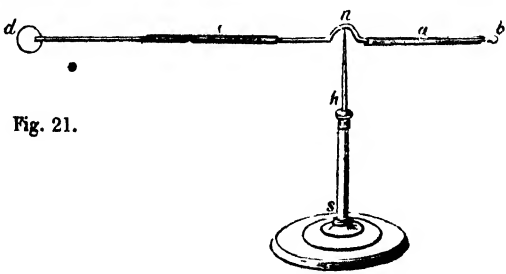


Fig. 21.

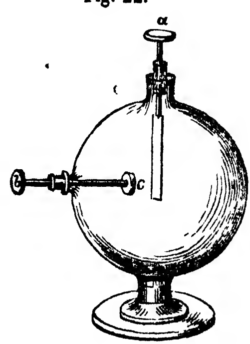
brass wire, *a n c*, fig. 21, are placed two light reeds *a b* and

c d, so as to form arms of unequal length: the long arm *c d* carries a light disc *d* of stiff gold paper, of about ½ an inch in diameter; the short arm *a b* carries a balance weight *b*, which may be a small shot or a ball of sealing-wax. The whole is delicately poised by a central point *n* upon a short piece of brass rod *h*, supported on a varnished rod of glass *h s*. The balance may be readily adjusted by sliding the reeds *a b* and *c d* upon the bent brass wire, so as to elongate or contract the opposite arms.

When this needle is used to detect the mere presence of electricity by its attractive force, a metallic thread is hung from the brass rod *h* so as to uninsulate the needle, and the excited or other electrical substance is presented to the disc *d*. If we require to determine the kind of electricity, we withdraw the metallic thread from *h*, insulate the needle, and electrify the disc *d* either positively or negatively: on again presenting the electrical substance to the disc *d*, it will be either attracted or repelled, according as the electricity is of the same or of an opposite kind to that with which the disc is charged (16).

Single Gold-leaf Electroscope.—An instrument of this kind was first described by Dr. Hare, of Philadelphia. It is best constructed in the following way. A slip of gold leaf, about 3 inches in length, and $\frac{3}{10}$ths of an inch wide, is suspended from the extremity of a small brass rod, within a glass cylinder or sphere, as in the annexed figure 22. Immediately opposite the lower end of the leaf a similar small rod of brass passes through the side of the sphere, carrying a gilt disc of wood or paper *c*, of about half an inch in diameter: both these slender brass rods terminate in small plates of brass or gilt wood, *a* and *b*, also about half an inch in diameter. The metallic rod at *a* slides through pieces of cork, contained within a

Fig. 22.



short varnished tube of glass, supported by a wooden cap; or a piece of cork may be placed in the straight neck of the glass. The second rod *b c* slides through cork in a similar way, either inserted in the opening originally formed with a neck in the side of the sphere, or in a cap of wood, cemented about the hole drilled through the glass. The whole is sustained on a convenient foot-piece. A common spherical lamp-glass with a hole drilled in its side, or a small chemical receiver, in which an opening in the side with a neck is already present, will be found convenient substitutes for a glass receiver made expressly for the purpose, as represented in the figure.

If we require to detect by means of this electroscope, which is to the highest degree sensible, the presence of electricity, a thread of metal is hung on the rod *b*, so as to admit of a free inductive action (23), and the electrical body is then brought into contact with the disc *a*. When the distance between the leaf and the disc *c* is made very small, the most minute force of attraction becomes apparent.

If we require to determine the *kind* of electricity, we slide the wire of the disc *c* so as nearly to touch the leaf, and then electrify gently the leaf or disc *c*, either positively or negatively, with moderately excited glass or wax. The leaf will then be repelled, and stand off from the disc (16). Under these circumstances, if we present the electrical body to one of the plates *a* or *b*, the leaf will either diverge more freely, or collapse towards the disc *c*, according as the electrical state of the substance under examination is of the same or of an opposite kind to that with which the leaf had been previously charged (17). In the use of this instrument care must be taken to preserve a dry atmosphere within the glass receiver, which may be, if required, removed from its foot, and held for an instant over a warm iron. The glass also, about the openings through which the brass rods pass, should be carefully varnished. With proper care, it is quite astonishing how sensitive the instrument becomes to the smallest electrical force.

Electroscopes of Divergence.—Two small balls of the pith

of elder, attached to a thread of silk or cotton, and hung over any appropriate insulating support, as in fig. 23, constitute an electroscope of divergence. If the balls be electrified either positively or negatively, they diverge (17); and any substance in an oppositely electrical state will, if brought near them, cause them to collapse more or less (17); whilst a substance in the same electrical state increases the divergence. These have been termed 'Canton's Balls,' from their being first employed by that skilful Electrician. The Earl of Stanhope constructed an electroscope of divergence by suspending two delicate reeds, terminating in pith balls, quite parallel to each other, as shown in fig. 24. This electroscope is more sensitive from the parallelism of the reeds, since the divergence will be more sensible when the legs of the electroscope hang parallel than when their upper extremities are in contact.

Fig. 23.

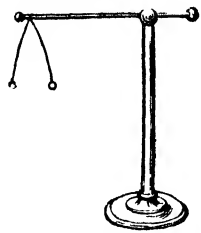


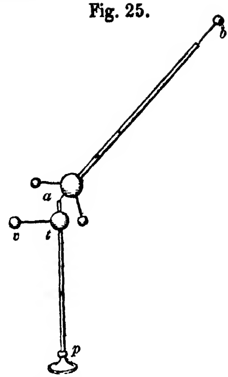
Fig. 24.

The electroscope adverted to, fig. 7 (17), will be found an extremely useful and convenient arrangement from the facility with which electricity may be conveyed to the suspended bodies through the medium of the short metallic wire to which they are hung.

Mr. Cavallo obtained a delicate suspension by hanging the balls on short pieces of silver wire, formed into a loop at the upper ends, and moving on a ring of the same wire, as a point of suspension: this method gives extreme freedom of motion.

A very delicate and simple electroscope may be thus constructed: cement a long light reed *a b*, fig. 25, upon the large end of a thick but finely pointed needle; pass the needle and reed centrally through a small cork ball, and balance the system about the needle point *a*, by means of two stout pins

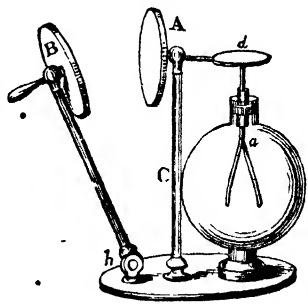
Fig. 25.



thrust obliquely into the cork, and having a small quantity of sealing-wax melted upon them, to insure the stability of the system. Let the whole be supported on a short brass wire *t a*, sustained on a slender rod of glass *p t*, so that by a short arm *t v* the whole may be put in communication with the ground, according as we require to exhibit an attractive or repulsive effect on a pith ball *b* fixed on the end of the reed.

Bennett's Gold-leaf Electroscope.—This is one of the most perfect and beautiful of this class of instruments. It consists of two slips of gold leaf, attached to short slips of paper, and suspended parallel to each other within a glass receiver by means of a rod of brass passing through a varnished glass tube, insulated in its neck, as represented in fig. 26. The end of the brass rod *a* is split open, and formed into forceps for holding the paper slips to which the leaves are attached, whilst the opposite extremity carries a small disc of metal or of gilt wood *d*, as in the single-leaf electroscope, fig. 22.

Fig. 26.



When we require to ascertain either the presence or kind of electricity, the electrified substance is brought in contact with the plate at *d*. The leaves then separate, as shown in the figure; the separation being permanent, at least for a short period of time. The kind of electricity is ascertained by presenting a gently excited rod of glass or sealing-wax to the cap *d*; the leaves will then either collapse or have the divergence

increased, according as the electricity with which they have been previously charged is *of the same or of the opposite kind* to that of either of these excited bodies (17). It may be requisite to observe that the sensibility of this instrument is such as to require extreme care in the progress of such experiments. We should only operate with very gentle electrical forces, just sufficient to produce a decisive effect on the leaves of the instrument, and no more. Such is its sensibility, that a slight flap with a silk handkerchief on the plate *d* will render the leaves divergent. The Rev. A. Bennett, the inventor, found it powerfully affected by the mere projection of powdered chalk upon the plate from a common brush, or by wind blown upon it from a common bellows. It may be employed with advantage for Experiments 9 and 11.

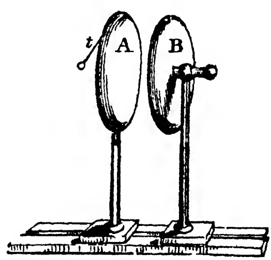
The slips of gold are easily managed in their application to this instrument, if the proper means be resorted to, otherwise the process of applying or replacing them is tedious and difficult. The gold leaf should be laid on a leather cushion, and handled with a flat clean palate knife, made very dry. The slip is cut, or rather divided, by the edge of this knife drawn with pressure over it parallel to one of the sides of the leaf; a small short slip of gilt paper, gently moistened at one end with the lips, is then applied to the gold slip, by which it may be readily raised off the cushion. In placing the two leaves in the instrument, it is desirable to separate them a little by a very thin slip of gilt cork, so as to allow of their hanging parallel and free, without absolutely touching.*

42. *The Electrical Condenser.*—We are indebted to Volta for this most important instrument, which is an application of the principle of approximated surfaces (21) to the detection of extremely small forces. It may be inferred from Experiment 15 (21) that an electrified conductor B, fig. 9, has a certain

* The management of leaf gold and other metallic leaf being of importance to the Electrician, he should provide himself with a hard leather cushion, a palate knife, and wooden forceps, such as are used by the gold beaters. The gold leaf employed should be firm, and of the best quality.

portion of the charge masked or neutralized when brought near a similar neutral body A in conducting communication with the earth. Under these circumstances, the effect of the distant surface c upon an electroscope may be not only very greatly diminished, but may be even reduced to nothing, or nearly so. In order, therefore, to affect the electroscope as before, an additional quantity of electricity is required, in consequence of the exclusive or compensating action between the opposed surfaces $a\ b$. Imagine, then, this additional quantity to be thrown upon the already charged conductor B, and the electroscope attracted in the same way as before. It is evident that if we now, under these circumstances, remove the opposed compensating surface a, that is to say, the body A, we shall immediately set free the previous quantity which it held in abeyance, and the electroscope will become attracted with the united forces of the whole, and so evince an increased effect. The near approximation of such a surface therefore enables an insulated conductor to absorb or receive a greater quantity of electricity under the same amount of activity, as shown by an electroscope, than it could otherwise support. In other words, it acquires an increased electrical capacity: this is, in fact, the principle of the condenser. Let two metallic discs A B, fig. 27, be placed extremely near each other, but so as not to touch, one of them, A, being insulated and sustained on a rod of varnished glass, the other, B, being supported on a metal rod, and hence uninsulated. If in this case a conductor or other body charged with a quantity of electricity so small as to be insensible to the most delicate electroscope be

Fig. 27.



applied to the insulated disc A, and be again removed, then, by the influence of the opposed disc B, that small charge will have been all absorbed by the insulated disc A, and will be

sensible to the electroscope *t* directly B is removed. This instrument, for the greater convenience of manipulation, is usually attached to the double gold-leaf electroscope, as shown in fig. 26,—the uninsulated disc being moveable on a hinge *h*, by which it may be turned back.

An efficient and powerful condenser of a simple kind may be formed by placing a circular disc of wood, covered with tin-foil or metallic leaf, very near a smooth table, which is easily done by allowing it to rest on three small fragments of common window glass coated over with sealing-wax, or otherwise varnished. This disc may be about a foot or more in diameter, and $\frac{1}{4}$ inch or a little more in thickness; it should be furnished with an insulating handle, D, fig. 31, page 67. If it be now required to examine any substance in so low an electrical state as not to affect a delicate electroscope, we bring it into contact with the disc, which, from its proximity to the table, can now absorb a quantity of electricity of which it was not otherwise sensible. If we now remove the disc by its insulating handle, and apply it to the electroscope, fig. 26, the leaves immediately diverge, by which both the presence and quality of a very minute quantity of electricity may be ascertained. If two plates of 1 foot in diameter be placed vertically, as in figure 27, and a fine trial leaf *t* be attached to the back of the insulated disc, we have at once a condenser and an electroscope of great sensibility and simplicity.

If, instead of transferring the plate immediately to the electroscope, we apply it to the second smaller condensing plate attached to the electroscope, as in fig. 26, and repeat the operation upon this second condenser, then it is quite astonishing how small a quantity of electricity may be detected, especially by repeated contacts with the first condenser, before turning back the plate of the condenser attached to the electroscope.

This process of multiplying the effects of very small forces has been extensively employed by Electricians in very refined electrical inquiries, and has given rise to instruments termed

'multipliers' and 'doublers;' these, although exhibiting great skill and ingenuity in construction, are still liable to considerable objection, being of themselves, from their extreme delicacy, liable to induce a low state of excitation, and hence to manifest equivocal results.

INSTRUMENTS FOR EXCITING AND COLLECTING ELECTRICITY.

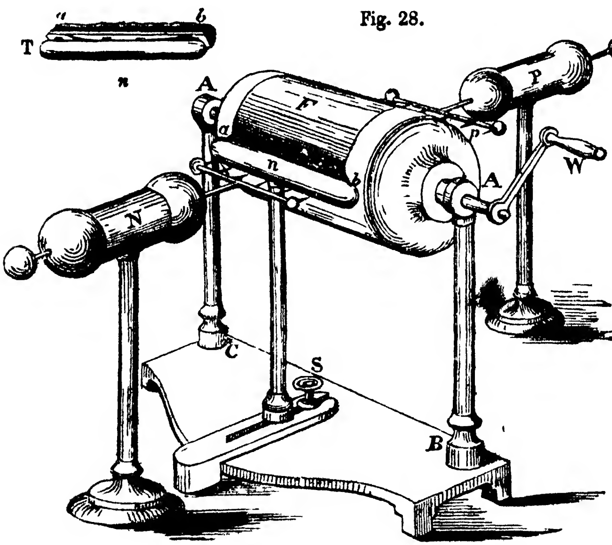
43. Any instrument for the excitation and collection of electricity is termed an *electrical machine*. Those machines in which the excitation is produced by friction consist, 1st, of some electric to be excited; 2ndly, a rubber or cushion by which the excitation is effected; 3rdly, an insulated conductor for collecting the excited electricity. Thus the glass tube, fig. 2, page 6, with its wire and ball excited by silk held in the hand, is in fact an electrical machine,—the tube being the electric, the hand and silk the rubber, and the attached metallic wire and ball the insulated conductor for collecting the excited electricity. If the tube be about $1\frac{1}{2}$ inch in diameter and about 2 feet in length, and be rubbed with the rough side of black oiled silk, smeared over with an amalgam of tin, zinc, and mercury (29), the excitation is by no means inconsiderable; strong electrical sparks will be thrown off from the conducting wire and ball, and other powerful effects will be obtained. In the early periods of this branch of science, glass tubes, brimstone, amber, and other electrics, subjected to friction by means of the hand, were commonly resorted to as an easy means of generating electricity by friction; but as further advances were made, and the great importance of the subject became apparent, a more complete and powerful kind of apparatus was naturally sought for. The first attempts of this kind consisted in the revolution of globes of glass, aided by some kind of mechanism. These were made to turn round against fixed cushions, the generated electricity being collected upon insulated conductors. We are indebted to a philosophical Burgomaster of Magdeburg, the ingenious Otto Guericke, for

the first idea of a machine of this kind. Having mounted a globe of brimstone on an axis, he caused it to revolve against the hand, and thereby obtained a rapid and powerful excitation.

A great variety of electrics have been treated in this way, giving rise to machines of different forms and construction, some of them of a very complicated and unwieldy kind. All these, however, have become finally resolved into one or two forms of apparatus now in use, in which the electric to be excited is either a hollow cylinder or a circular plate of glass. We shall, for the sake of perspicuity, confine ourselves to a description of a few of the most perfect of this class.

44. The annexed fig. 28 represents a cylindrical electrical

Fig. 28.



machine of an improved kind, in which A A is a hollow glass cylinder, having wide open ends fitted with caps of wood. These caps have projecting pivots, which serve as the extremities of a horizontal axis, and turn in pivot-holes drilled in

spherical pieces of wood or metal, A A, cemented on vertical glass pillars, A B, A C, the whole being fixed on a firm wood base, C B. A flat cushion, or rubber of coarse oiled silk T, stuffed with wool or hair, and backed by a wooden cylinder *n*, covered with tin-foil, is fixed at *a b* on a vertical glass pillar S *n*, attached by a sliding piece S to the base C B, by which it is caused to bear with greater or less force against the glass cylinder. There is a screw at S for confining the slide in any given position. The rubber *a b* is supported loosely against the wood cylinder by two brass pins, and is furnished with a long flap of thin silk F, oiled on one side only, sewed to its outer edge: this rests upon and passes over the upper surface of the cylinder, the rough side being next the glass. Immediately opposite the termination of this silk flap there is a small cross arm of brass *p*, carrying three or four short points for catching up the vitreous or positive electricity from the glass as it emerges from beneath the silk flap, and transmitting it to the insulated cylindrical conductor P. A similar cross arm transmits the negative or resinous electricity of the rubber to the insulated conductor N: the cylinder is set in motion by a winch W, having an insulating handle of glass, and fixed to one of the projecting pivots. Each cap of wood consists, together with the pivot, of a single piece, and is fitted securely in the projecting glass necks by attached pieces of fine cork, so as to admit of the cap being occasionally removed, and the interior of the cylinder rendered very dry and clean. For a perfect development of the power of such a machine, it is requisite to free the glass from all dirt and moisture, both on its inner and outer surface. The cushion or rubber should be covered with the amalgam of tin, zinc, and mercury, already described (29), which may be spread on it by the aid of a little lard, and the surrounding air should be rendered as dry as possible.

45. When under these favourable circumstances we put the cylinder in motion, the conductors P and N being removed, brilliant scintillations and lines of light will dart round the

under surface of the cylinder, between the termination of the silk flap and the rubber; brushes of light and luminous coruscations will frequently appear to fly off into the air from under the flap, presenting in the dark an extremely beautiful appearance. If a pointed metallic rod be held in the air in front of the silk flap, a bright star of light will appear to settle on it, even at a considerable distance from the glass. When the conductors are placed as shown in the figures, and the knuckle of each hand presented, one to the conductor P, and the other to the conductor N, a current of bright and powerful sparks will pass between the knuckles and each of the conductors; and if we observe at this time the points on the cross arms, those on the positive conductor P will appear as simple luminous points or stars, whilst those on the conductor N will be divergent, and present to the eye the appearance of a luminous brush. If we suspend a chain of small metallic beads, strung together on a silk thread, between two metallic rods fixed on the conductors P, N, it will appear as a sort of brilliant necklace of luminous beads, the effect of which is frequently dazzling to the eye.

When we require to collect vitreous or positive electricity, we present the substance to be charged or electrified, to the positive conductor P, and connect the negative conductor N, or otherwise the cushion itself, with the earth, by which means electricity becomes continually supplied to the revolving glass cylinder. When we require negative or resinous electricity, we reverse this arrangement. The body to be charged is presented to the negative conductor N, and the positive conductor P connected with the earth, so as to relieve the surface of the glass cylinder of the electricity thrown on it, and enable it to develop a continual excitation in the rubber, and consequently a constant supply of negative electricity to the conductor N.

46. It has been usual in constructing these machines to form the end of the glass cylinders into narrow necks, and close them up; but it is far preferable to have them wide and capacious, so as to admit of drying and wiping out the in-

terior. The condensation of moisture on the interior of the surface is fatal to the action of the machine, from the conduction it affords to the return of the induced electricity over the interior of the glass to the cushion. In fact, if the conductors P and N be joined by a curved wire, all the phenomena we have just described will vanish. It was probably from this circumstance that some of the early Electricians found their glass globes and cylinders improved in power by coating the interior with some resinous composition, by which the non-conduction of the vitreous surface was rendered more perfect, and moisture less liable to condense on it. Electrical machines of this construction are made with glass cylinders varying from 4 inches to a foot or even to 20 inches in diameter, and from 6 to 18 inches in length.

47. *The Plate-glass Electrical Machine.*—About the year 1776, Van Marum was led to employ a circular disc of shell lac as a convenient form of electric for excitation. This was soon followed by a disc of plate glass. Ingenhouz, Van Marum, Ramsden, and Cuthbertson, appear to have been the originators of electrical machines of this kind. The machine, as constructed by Cuthbertson, about the year 1783, consists of a circular disc of plate glass, from 2 to 7 feet in diameter, mounted on a horizontal axis of metal, and sustained by a vertical frame of mahogany, to which are fixed two pairs of cushions or rubbers, one pair above, the other below. This plate is turned round between the rubbers by a winch fixed at the extremity of the axis. The electricity is confined by flaps of oiled silk, extending from each pair of cushions round one-fourth nearly of the circumference of the plate, and is then collected by two rows of points opposite its horizontal diameter, and communicating with an insulated metallic conductor.

In this arrangement we have only the vitreous or positive electricity of the plate. To obtain the resinous or negative electricity of the cushions, it is requisite to connect them by a slip of metal let into the frame-work, and to place the whole machine on pillars of glass. In this case the conductor,

which was before insulated, must communicate with the ground.

This machine is prepared for excitation as already described (44). Its action is very intense, and the same phenomena as observed with the glass cylinder are observable on turning the plate,—the effects being doubled by the addition of another set of cushions, although it has been doubted whether the friction on *both* sides of the plate is attended by any greater effect than a well-applied friction on one side only. This form of electrical machine, however, is undoubtedly extremely powerful, and well adapted to extensive researches in electricity; but for ordinary philosophical purposes, the cylindrical machine, from the simplicity of its construction and use, is probably more convenient.

48. Van Marum, about the year 1785, constructed, with the aid of Mr. Cuthbertson, an electrical machine on this principle, of enormous power, and which was afterwards placed in Teyler's Museum at Haarlem. It consisted of two circular plates of French glass, each 65 inches in diameter, fixed upon the same axis, and excited by four pairs of cushions, each cushion nearly 16 inches in length. The conductor was supported on three pillars of glass, sending out collecting branches between the plates. Two men, and sometimes four, were employed to turn the plates. When in full force, a single spark from the conductor was found to melt a leaf of gold; a thread became attracted at a distance of 38 feet; and a pointed wire exhibited the appearance of a luminous star at a distance of 28 feet from the conductor. Persons within 10 feet of the plates experienced a sort of creeping sensation over them, as if surrounded by a spider's web.

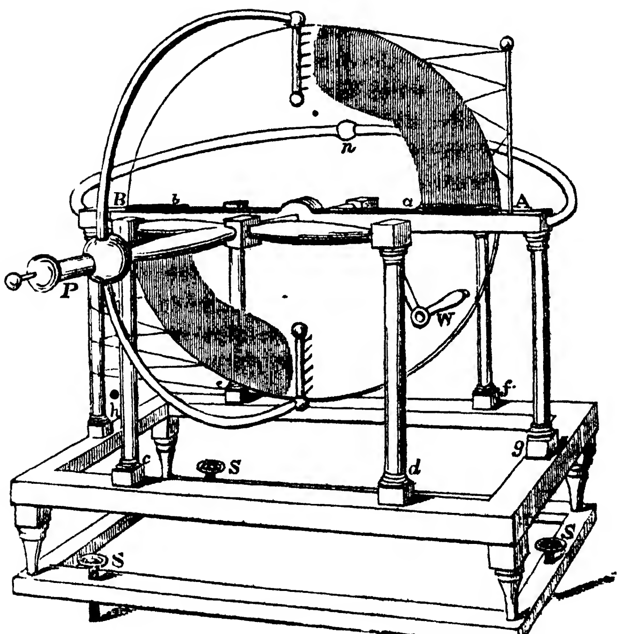
49. The collection of negative electricity from machines under this kind of arrangement being attended with inconvenience, several attempts have been made to vary it. Van Marum was hence led to place a single plate at the extremity of a strong horizontal axis; and having insulated the cushion or glass pillars on each side of its horizontal axis, collected

either positive or negative electricity by a double-branched wire in connection with the conductor, which could be turned either upon the rubber or the glass,—whilst another wire behind the plate could be placed in a similar way, so as either to supply the rubber, or discharge the electricity excited in the

In other arrangements a single pair of cushions only is employed, with a large conductor immediately opposite. The great plate used at the Royal Polytechnic Institution in Regent Street, London, is mounted in this way. It is 7 feet in diameter, is turned by a small steam engine, and is extremely powerful.

50. The following arrangement, fig. 29, will be found

Fig. 29.



effective, and calculated to meet every difficulty in the use of the glass plate for positive and negative electricity. In this construction the plate is mounted on a metallic axis, supported between two transverse bars of mahogany, on four vertical mahogany pillars, *c d e f*, as represented in the figure. These pillars are inserted into a strong rectangular frame, two before and two behind the plate, forming a firm and secure basis. The rubbers A *a* and B *b* are placed on each side, and insulated on stout pillars of glass, A *g* and B *h*, also fixed to the hollow rectangular frame. A metallic conductor P, with two branches, is sustained in a vertical position in front of the frame, on a strong support of glass, whilst a curvilinear brass tube, A *n* B, passing behind the plate, connects the cushions, and forms the negative conductor.

The plate is turned round by an insulating winch W, constructed of a strong cylindrical bar of glass, and the whole is supported by four legs on a second rectangular frame, having three levelling screws, S S S, fixed in it, so as to render the axis level and the machine secure on the ground. This machine is employed in the same way as that already described (44). With a plate of about 2 or 3 feet in diameter, very extraordinary power is obtained.

In all machines of this construction it is requisite to attach cords of silk to the flaps, and pass them round fixed supports, in order to prevent the flaps from being dragged over the plate in turning it round.

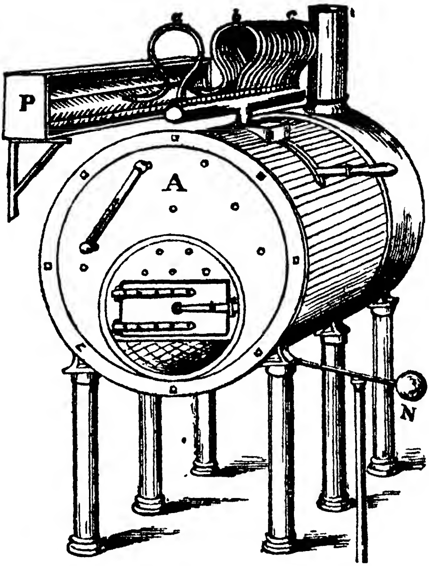
51. It may be as well to state here that the power of electrical machines will greatly depend on the kind of glass of which the plate consists. If plate glass be employed, it should be of a flinty kind, of very perfect manufacture, and be very highly polished. A common vitrified surface, from its very perfect polish, is perhaps more powerful than polished plate; hence plates of common window glass, joined by an intervening cement of black sealing-wax, are well adapted to the purposes of electrical excitation. A plate machine con-

structed in this way, with a plate of about 2 feet in diameter, had most remarkable power.

52. *Hydro-electric Machine.*—This species of electrical machine is of very recent date and construction, and is the result of an accidental discovery in 1840, by an observing workman in charge of a fixed steam engine at Sighill, near Newcastle. Owing to a leak in the cement about the safety-valve, there arose a considerable escape of steam. The engine-man, being about to adjust the weight of the valve, was surprised by the emission of a powerful spark of electricity, which he found always to arise from the metal-work connected with the boiler, and from the boiler also, if he attempted to touch it during the escape of steam, especially when one of his hands was immersed in the vapour. Mr. Armstrong, a scientific gentleman at Newcastle, having been informed of this result, lost no time in investigating the phenomenon. By an insulated brass rod, having a metallic plate at one extremity and a ball at the other, he obtained 60 or 70 sparks per minute on bringing the ball near the boiler, whilst the plate was immersed in the issuing vapour, and after a series of highly interesting inquiries, he succeeded in producing a vaporizing electrical machine, depending on the excitation of particles of water driven by steam through small orifices. This machine consists of a steam boiler A, fig. 30, insulated on stout pillars of glass. The steam is caused to issue from a general steam pipe through bent iron tubes *a b c*, terminating in jets of wood, and of which there are a great number: an insulated projecting conductor N is placed in connection with the boiler, for the convenience of collecting the excited electricity; and a second conductor P, formed of a metallic case, furnished with several rows of points, is placed immediately in front of the jets, to receive and carry off the opposite electricity of the steam, and prevent its return upon the boiler, by which the excited forces would be neutralized. Faraday, who also investigated this question with his accustomed tact and penetration, has shown, by a series of masterly experiments, that the electricity thus

produced does not depend on the mere issue of steam through small orifices, or upon any chemical or other change which

Fig. 30.



may be supposed to arise from evaporation or condensation, but is the result of the friction of condensed particles of water whilst being driven by the still issuing steam through the jets; so that in fact these watery particles perform the office of the glass plate of the common machine, and give out vitreous electricity: the wood jets and pipes act as the rubber, and give out resinous electricity, whilst the friction of the steam in passing is the source of the electricity.

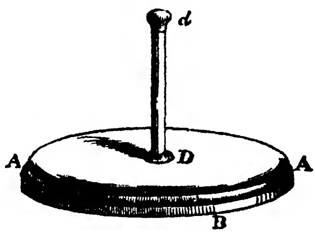
The electricity produced by this apparatus is enormous in quantity. The sparks from the conductor N, upon an uninsulated metallic ball, are dense and rapid, presenting frequently the appearance of a continuous flame, and will readily set fire to inflammable matter.

THE ELECTROPHORUS.

53. The *electrophorus*, or perpetual electrical machine, is another most valuable instrument, for which we are indebted to the ingenuity of Professor Volta.

The arrangement consists of a circular or other electrical plate A A, fig. 31, usually of shell lac. This plate is placed on a conducting disc B, of about the same size, and termed the sole; a second circular conducting disc D, termed the cover, and furnished with an insulated handle D *d*, is placed upon the upper surface of the electrical plate. When this instrument is employed for the production of electricity, we first remove the cover D by its insulating handle, and then excite the electrical plate A A by flapping it briskly with dry silk or with some dry fur-skin; we then replace the cover D as before: the cover, being insulated, does not take up the electricity of the plate, but is acted upon inductively (21), that is to say, its neutral condition is changed, and the parts distant from the under surface placed in the same electrical state as the surface of the excited plate: hence these parts are in a condition to charge any substance brought near them. We find, accordingly, that on bringing a conductor near the cover, an electrical spark is elicited, which tends to neutralize the induced state of its parts distant from the surface in approximation with the electrical plate beneath; and if such conductor be insulated, it will become charged with the same electricity; that is to say, if the electrical plate be negatively excited, the distant parts of the cover D will be negative by induction (21), and any conductor brought near it will yield up positive electricity, and remain also negatively electrified. If we now remove the cover D by its insulating handle, we immediately

Fig. 31.



restore its original capacity, whilst the positive electricity it had acquired under induction remains. Hence it is now charged with positive or vitreous electricity, and will electrify any insulated conductor positively when brought near it.

It is quite evident that in this machine the excited electric loses nothing of its electricity by all this, the excitation being merely subservient to induction. Hence, after restoring the neutrality of the cover by relieving it of its charge, we may again repeat the operation, and carry off in this way successive charges without any new excitation of the electric plate: it is hence a sort of permanently excited electrical machine.

The electrical plate of this instrument, as constructed by Volta, consisted of shell lac, common resin, and Venice turpentine, in equal parts. The sole may consist of a circular plate of wood, covered with tin-foil. The cover, or superior conductor D, may be also a light disc of wood, covered with some stout metallic leaf. Small plates of glass, sealing-wax, or brimstone, are admirably adapted to experimental purposes, when mounted as electrophorus plates, with the attendant conductors. The machine itself has been termed *electrophorus*, from the circumstance of its prime conductor, the cover, *bearing off* as it were by repeated removal definite quantities of electricity which it had absorbed under the influence of the excited electrical plate.

ELECTRICAL MACHINES WHICH DO NOT DEPEND ON FRICTION.

54. Although electrical excitation by friction has been generally employed in the construction of ordinary electrical machines, yet other sources of electricity are open to us. Thus the dry electrical pile, fig. 15, and the voltaic series, fig. 16, may each be considered as electrical machines, although of very limited power for common electrical purposes. The electrical disturbance also induced in a coil of wire by magnetism, fig. 17, may be employed as a source of electricity, and has given rise to the magneto-electrical apparatus already

alluded to (28). Such instruments, although admirably adapted to some peculiar experimental researches, are quite unavailable in the accumulation of great statical electrical power.

THEORETICAL VIEWS OF THE ACTION OF ELECTRICAL MACHINES.

55. The production of electricity by the ordinary electrical machine is explicable upon either the double or single fluid hypothesis (32) (33). According to the first of these (32), we disunite by friction the combined electricities existing in the rubber and glass, and change, according to the improved theory (37), the relative attractive power of these substances for the separated elements, so that the positive force becomes collected on the glass and the negative force on the rubber; but since there is only a certain quantity of electricity in the glass and rubber, the action must cease after a few revolutions of the glass, unless more electricity be furnished for decomposition; and such is found to be the case: very little effect is produced so long as the positive and negative conductors P N, fig. 28, remain insulated. Directly, however, we connect one of these conductors with the ground, the other will be in a position to charge any insulated substance presented to it up to a point of saturation; for the neutral state of the one conductor becomes restored at the expense of the opposite electricity drawn from the mass of the earth, and that of the other at the expense of the opposite electricity of the insulated body: hence both the mass of the earth and the insulated body may be considered as being electrified by this operation—the one positively, the other negatively, according to the particular conductor, P or N, with which they are associated. But the electricity of the earth being indefinitely great, the result is only sensible on the lesser insulated body, and the action is limited to the quantity of positive or negative electricity which it can furnish.

If, instead of connecting one of the conductors with the

earth, we associate it with another insulated body, then the effect is sensible in either case, and the action is limited to the quantity of positive or negative electricity which the insulated substances can yield up: such is, in fact, the condition of the positive and negative conductors P N, which yield up negative and positive electricity to the glass and rubber, directly the machine is put in motion, and by which the one, P, becomes charged positively, and the other, N, negatively. If both these conductors therefore be connected with the ground, the result is a continual separation and re-composition of the two forces, and hence a neutral state of the conductors P N. Upon this theory, therefore, the action of the electrical machine consists in a separation and abstraction of one of the electrical elements, leaving the other in excess.

56. The electrical machine, according to the hypothesis of a single elementary fluid, is only a means of changing the quantity of electricity in bodies. By the revolution of the glass against the rubber we continually renew and break the contact between these substances, the consequence of which is an accumulation of electricity on the glass, and an abstraction from the rubber (18). Hence the insulated conductors P and N, fig. 28, become charged, one positively or plus, the other negatively or minus. On this, however, as on the former hypothesis, the action would soon cease if one or both of the conductors remained insulated, since the rubber has only a limited quantity of electricity to yield up, and the glass therefore only a certain quantity to gain: reciprocally, the glass cannot take up more than a given quantity of electricity, consequently the rubber can only lose a limited quantity. Hence the excitation is confined within these limits. Now imagine two insulated conductors brought near the conductors P N; one near the positive conductor P, the other near the negative conductor N. The result would be an abstraction of electricity from the body opposed to the negative conductor, which would go to restore the equilibrium in the rubber, and an addition of electricity to the body near the positive conductor, which would relieve or

neutralize the electricity of the glass; and thus the action of the machine would be to charge or electrify both these bodies at the expense of each other, the one positively, the other negatively. We have still, however, reached a limit depending on the amount of electricity which the respective bodies can yield up or receive. Such is in fact the condition of the conductors P N, one of which, P, receives the excited electricity on the glass, whilst the other, N, yields up electricity to the rubber. When, therefore, we connect one of these conductors with the earth, the action may become indefinitely great upon any insulated body applied to the other, and required to be electrified, however great its extent, the means of supply of electricity being without assignable limit. When both the conductors P N are connected with the mass of the earth, the result is a constant disturbance and renewal of electrical neutrality,—the rubber being supplied with electricity as fast as it yields it up to the glass, and the glass yielding it up again to the earth as quickly as it abstracts it from the rubber. Upon this hypothesis, therefore, the operation of the electrical machine is that of a pump,—to withdraw electricity from some bodies and throw it upon others.

57. These two theories apply in nearly the same way to the action of the electrophorus. The cover D, fig. 31, whilst on the excited plate, acts upon bodies in the same way as the negative conductor N, of the electrical machine, fig. 28, supposing the plate to be a resinous electric; after removal, it acts as the positive conductor P; that is to say, on the hypothesis of two electric fluids, it first attracts vitreous electricity from any body applied to it, in consequence of its distant parts having become negative by induction (21), and hence will leave such body charged with resinous electricity. On removal it attracts resinous electricity from any body presented to it, in consequence of the charge of vitreous electricity it had previously taken up, and so electrifies such body, if insulated, positively. On the single fluid hypothesis (35), the cover first attracts and then gives out electricity;

that is to say, it first abstracts electricity from some bodies, and then communicates it to others.

The induced action upon which this state of the cover depends, is, upon the hypothesis of two fluids (32, 37), derived from the excited electricity of the electrical plate. Supposing the electrical plate to be a resinous plate, the vitreous electricity of the cover is attracted towards it, leaving the resinous electricity repelled to its distant surface. On the single fluid hypothesis (33), (36), the electrical plate being deficient of electricity, or minus, the electricity of the cover is drawn towards it so as to equalize the distribution as nearly as possible, hence leaving its distant surface negative or minus.

If the electrical plate be excited with vitreous electricity, then the converse of all this happens, but the theoretical views remain the same.

58. Similar applications of these theories may be made to the electrical pile, and to the coil of the magneto-electric machine (28). We have, upon the one theory, a separation of the combined electricities, and upon the other an unequal distribution. In the electrical column and voltaic series (28), the opposition of the two metals changes their relative capacities for one of the electrical elements, or for electricity considered as a single elementary fluid, so that either positive or negative electricity exists in excess, or flows upon one of the metals. By the intervening semi-conducting fluid or other substance this excess is carried on to the next pair of metals, and so throughout the whole series up to the terminating plates, which become finally charged with different electricities, analogous to the positive and negative conductors of the electrical machine. We have, however, in such arrangements a sort of electromotion, together with a development of electricity by chemical action when the plates are excited by saline and other fluids.

In the coil of the magneto-electric machine a somewhat similar electric motion is produced by the influence of the magnet; and each end of the coil, at the instant of making

or breaking contact with the magnet, is in opposite electrical states.

THE ELECTRICAL JAR, OR LEYDEN PHIAL.

59. The years 1745 and 1746 are remarkable for a scientific discovery of a very marvellous character. Some Dutch philosophers at Leyden finding electricity rapidly disappear from a simple insulated conductor, imagined that if it could be completely enclosed in solid electric matter, a charge might be retained on the conductor for any length of time. This idea, early in the year 1746, they endeavoured to realize. Water being a convenient conductor, they enclosed it in a small glass phial, and having inserted a nail through the cork, suspended it from the prime conductor of the electrical machine so as to convey electricity into the water through the nail. One of the experimenters, Mr. Cunæus, whilst continuing this inquiry, in endeavouring to detach the phial and nail from the electrical machine, received so violent a shock across his arms and breast that it shook his whole frame.

A similar result appears to have been obtained about the year 1745, by Von Kleist, dean of a cathedral in Germany, whilst engaged in an interesting course of experiments on the communication of electricity to glass, an account of which is found in the register of an Academy at Berlin. Having passed a stout brass pin or wire into a common phial containing a small quantity of mercury, electricity was thrown, by means of the electrical machine, upon the interior of the phial, through the pin. His account of the results which ensued is both instructive and amusing. "As soon," says he, "as this little glass with the pin is removed from the electrical machine, a flaming pencil issues from it for so long a time, that I have been able to walk 60 paces in the room with this little burning machine; and if the finger or a piece of money be held against the electrified pin, the stroke coming out is so strong that both arms and shoulders are shaken thereby. Thin-necked glasses have been twice broken by the powerful shock."

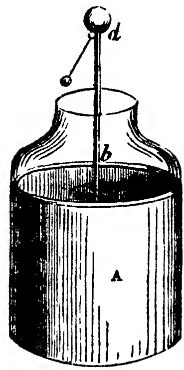
Muschenbroek, who subsequently repeated these experiments at Leyden, with water in a thin glass bowl, says, he was so struck in his arms, shoulders, and breast, that he lost his breath, and was two days in recovering from the effects of the blow.

The discovery of such a terrible power in nature soon spread through Europe, and gave immense impulse and éclat to electrical investigations. Sir W. Watson, Smeaton, Bevis, Wilson, and Canton, all distinguished members of the Royal Society of London, repeated and extended these experiments; indeed, it is to them that we owe the final completion of the Leyden phial, under the present form of the electrical jar, and its consequent practical application to researches in Electricity. Sir W. Watson showed that the power of the phial did not depend on the density or quantity of conducting matter either within or without the glass, but that, *cæteris paribus*, it was as the extent of contact between conductors and the surface of the glass; on which principle he placed the phial in a small open cylinder of sheet lead. Smeaton now transformed this experiment into the covering of plates of glass with thin metal, leaving on each side an uncovered part, and he found that if, after having communicated electricity to one of the surfaces of the plate, he touched both surfaces with his hands at the same time, all the effects of the Leyden or German experiment were obtained. Sir W. Watson, further enlightened by this result, now applied coverings or coatings of metallic leaf to the interior and exterior surfaces of glass jars, leaving a portion of the glass under the mouth of the jar free,—an arrangement both effective and convenient, and in use at this day.

Thus the Leyden phial resolved itself into the electrical jar, and became a most important instrument of physical research.

60. The most perfect kind of electrical jar is shown in the annexed figure 32, in which the faintly shadowed portion A marks the position of the exterior and interior coatings,

Fig. 32.



usually tin leaf pasted against the glass: *b* is the uncoated or insulating portion of the jar; *d b* a light metallic rod or tube, terminating in a knob or metallic ball *d*, and passing to the bottom of the jar, where it is supported in a socket of wood, fixed to the coating expanded upon the glass. This is the charging rod, and care is taken to insure a good contact with the metal on the bottom of the jar.

When the jar is to be charged, the charging rod *d b* is connected with one of the conductors of the electrical machine, and the exterior coating A with the ground, taking care to operate with the machine in the way already explained (45). The progress of the charging may be observed by means of a light reed terminating in a small ball of pith, loosely attached to the charging rod by a very short piece of fine silk or cotton thread: this will constitute, with the rod, an electroscope of divergence (41), so that as the charge proceeds the reed will become raised, more or less, into the air, as represented in the figure. If the knob of the jar be placed within about half an inch of the conductor of the machine, a succession of sparks will be observed to pass into the jar: these will become gradually weaker when the jar is fully charged.

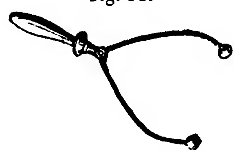
61. The charge being thus accumulated, the jar is again discharged by completing a conducting communication between the exterior coating A and the charging rod *d b*: the extent of such communication, which is termed an *electrical circuit*, may be almost indefinite. If the discharge be effected through a short circuit of bent metallic wire, terminating in metallic balls, an intensely brilliant explosion ensues, the light of which is almost insufferable; and there is heard at the same time a sharp crashing report. If a portion of the living frame be included in the circuit, then a powerful shock

ensues, the intensity of which depends on the amount of the charge.

Sir W. Watson, assisted by other members of the Royal Society, completed electrical circuits of several miles in extent. In August, 1747, they caused an electrical jar to discharge through a circuit of 4 miles, and found the effect to be instantaneous. The Abbé Nollet passed the charge through the whole community of a convent, forming a line of nearly 6000 feet. The shock was simultaneous.

In order to avoid the chance of receiving the shock at the time of discharging an electrical jar, two bent wires are employed, terminating in brass balls, and connected by an intermediate joint, so as to open or shut to any convenient distance, like a pair of compasses. These wires are mounted at the joint upon a glass rod or handle, as shown in fig. 33, and constitute what is termed a *discharging rod*. The balls are either extended directly between the exterior coating A and the knob of the jar, or one of them is connected with the termination of any extent or kind of circuit proceeding from the exterior coating; and the other applied, as before, to complete the discharge.

Fig. 33.



62. It is of no consequence which coating of the jar we first expose to the process of charging. If, for example, we turn over the jar, fig. 32, on its charging rod *d b*, and expose the outer coating A to the conductor of the machine, it is of no consequence whatever to the progress of the charge. When, however, we charge a jar in this way and wish to revert it so as to place the jar again upright on its base, we must take care to employ an insulated stand or table; for, as is evident, in reverting a charged jar upon a conducting base we complete the circuit through ourselves, and hence discharge the accumulation as before.

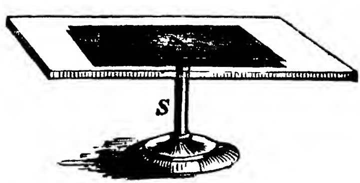
In whichever of these two ways we may find it convenient to complete the charge, we shall always have a surplus spark

upon the coating exposed to the charging conductor, and which may be made to appear by placing the jar upon an insulator, and presenting the knuckle to the coating through which the charge has accumulated.

63. When a charge is communicated from the prime conductor, the jar is said to be charged positively, or with vitreous electricity. If from the negative conductor, it is said to be charged negatively, or with resinous electricity. In either case it is equally powerful as a means of accumulating and discharging electricity, in a dense and concentrated form, upon or through any given substance: some idea may be formed of it in observing, that whilst a jar of only moderate size is charging at about half an inch distance from the conductor, several hundred electrical sparks will pass from the machine, and that at the instant of the discharge all these sparks are condensed into one.

64. *Theoretical views of the electric jar.*—It is quite apparent that the principles and arrangement of the condenser just described (42), fig. 27, are in no sense different from those of the Leyden jar. The arrangement is, in fact, virtually the same as that practised by Smeaton (59), except that we have given metallic coatings A and B, fig. 27, to a plate of air, instead of coating a solid plate of glass. In either case the arrangement is nothing more than the close approximation of an uninsulated to an insulated conductor; the success of the experiment does not therefore depend on the form of the glass, but rather upon its thickness. In applying metallic coatings to opposite sides of a plate of glass, as represented in the annexed figure 34, and connecting one of the sides with the ground by placing it on a metallic support S, Smeaton really fulfilled the essential conditions of electrical accumulation. In this case the upper coating A is the

Fig. 34.



insulated conductor, corresponding with the disc A, fig. 27, the inferior coating resting on the metallic stand S, is the uninsulated approximated conductor corresponding with the disc B, whilst the intermediate glass is in the same relative position as the particles of air between the plates; that is to say, it is the non-conducting or electric medium.

A square of glass thus prepared has been termed a coated pane, and by the French Electricians, a 'fulminating square.' It is charged and discharged in the same way as the coated jar, by first throwing electricity on the insulated coating A, and then joining the opposite sides with the discharging rod, fig. 33.

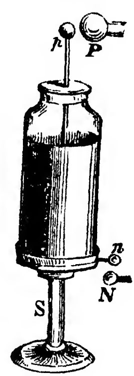
65. The Franklinian theory of electricity (33), in its application to the phenomena of the Leyden jar, may be considered as peculiarly happy and illustrative: according to this theory, electrics are supposed to be impenetrable to electricity or nearly so; whilst the quantity they contain can neither be absolutely increased nor diminished. When therefore we attempt to force upon any given electric a quantity of electricity greater than that which the body already contains, we actually displace such portion of its natural electricity as is requisite to make room for this new quantity. The Leyden experiment, therefore, according to this hypothesis, consists in the addition of electricity to one surface of the glass, and the abstraction of an equal quantity from the other surface.

Franklin, by a well-conceived and extremely beautiful series of experiments, showed, that if either side of a coated jar be electrified positively, the other side is electrified negatively, so that there is really no more electricity in the jar than before. To realize this idea more completely, let us imagine that an electrical jar originally possessed 100 units of electricity, 50 of which occupy strata beneath one of its surfaces, and 50, similar strata beneath the other. Then, when by the operation of the electrical machine we cause the whole or a part of the 50 units to leave either side and appear on the other, the jar is said to be charged to a greater or less extent. If we collect the total or 100 units on one side, it is said to be charged to saturation.

Now the discharge consists in a transfer of the redundant units to the minus surface from whence they were taken, by which the equilibrium of distribution is again restored.

66. The following experiments, resorted to by Franklin in confirmation of this doctrine, are singularly interesting and instructive.

Fig. 35.



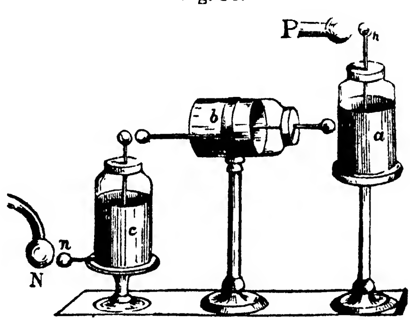
Exp. 28. Place an electrical jar, fig. 35, on an insulating support S; let the ball *p* of the charging rod be within about half an nch of the prime conductor P of the electrical machine. Bring another insulated metallic ball N, connected with the negative conductor, within the same distance of a similar ball *n*, projecting from beneath the outer coating. Put the machine slowly in motion, and for every spark which passes between the prime conductor P and the charging ball *p*, a similar spark will pass, at the same instant, between the outer coating *n* and the negative conductor N.

Exp. 29. When the jar has become in this way moderately charged, remove it and its insulating support S from the balls P and N of the positive and negative conductors, and having insulated a light metallic ball of about 2 inches in diameter on a glass rod, bring it near the ball of the charging rod *p*; a powerful spark will follow it, and charge the ball positively. Whilst thus charged, bring the ball near the ball *n* connected with the outer coating; the same spark will leave it again, as may be proved by the charged ball having again become neutral: hence precisely the same quantity of electricity taken up from the interior coating has been added to the exterior. In this way, by successive repetitions of the experiment, we may gradually discharge the jar; that is to say, we may take away by small and measured quantities all the electricity communicated to the inner coating, and throw it on the outer. Now if we examine, by means of an electroscope (17), (41), the inner and outer coatings of this jar,

especially after each alternate contact with the insulated metallic sphere, they will be found in opposite electrical states; that is to say, if the jar be charged from the prime conductor positively, then the outer coating will always evince negative electricity.

Exp. 30. Insulate two or three equal and precisely similar jars, *a b c*, fig. 36, and arrange them so that the charging ball of the second, *b*, may be within half an inch of the outer coating of the first, *a*, and the charging ball of the third, *c*, within a similar distance of the outer coating of the second, *b*. Let the outer coating of this third jar, *c*, be electrically placed, through the intervention of a conducting rod and ball *n*, within the same distance of an insulated ball N connected with the negative conductor, as the charging ball *p* is of the positive conductor P. Put the machine in motion, and directly a spark passes upon the inner coating of the first jar *a*, a similar spark will appear to leave the outer coating to charge the second jar *b*: this will again cause a spark to pass from its outer coating upon the charging ball of the third jar *c*, which will throw off the electricity of its outer coating upon the negative conductor N, to supply the rubber (45), and is the compensating quantity to the electricity abstracted from it by the glass to be thrown upon the interior of the first jar *a*; so that every jar will be equally and similarly charged, or nearly so, at precisely the same instant, and, by the propagation as it were of electrical impulse, through the series of jars. Now as the second jar *b* has become charged from the outer coating of the first, *a*, and the third jar *c* from the outer

Fig. 36.



coating of the second, *b*, it may be inferred that for every unit of electricity, added to the inner coatings, a similar unit has left the outer, which is what Franklin wished to show. This experiment, although satisfactory when only two or three jars are employed, is greatly embarrassed by extension upon a long series; the accumulated resistance of each jar being at length so considerable as to vitiate the result. When the resistance becomes at all equal to the charging power, the last jars of the series do not become charged in the same degree as the first, and the whole operation is thereby arrested.

Exp. 31. Apply an outer metallic coating only to a glass jar; varnish all that portion of the glass above the coating, both inside and out; place the jar on an insulated stand, and fill it carefully with water up to the height of the exterior coating; pass a metallic charging rod into the water through a light disc of varnished cork fitted into the neck of the jar; connect the external coating with the ground, and charge the jar as in Exp. 28 (66): when charged, cut off the connection with the ground, and remove the charging rod by its insulating handle: finally, remove the jar; place a precisely similar jar on the insulating stand, as at s, fig. 35 (66), prepared with an exterior coating only, and then, holding the first jar by its outer coating, pour off the water carefully into this second jar. Let the charging rod and cork be then applied to the water in this second jar; little or no electricity will have passed over with the water, more especially if the operator stand on an insulated stool, as may be found by the usual electroscopes (17), (41): remove this jar from the insulator; replace the first jar and pour other water carefully into it, as before; replace also the metallic charging rod. The jar will be found still perfectly charged; all the electricity, or nearly so, will have remained on the glass, and the whole system may be discharged in the usual way (61). The student must be careful to preserve the insulations in this experiment, otherwise in pouring over the water the electricity expands over both the jars.

This was the original form of the experiment, as made by Franklin, in evidence of the disturbed distribution on the glass, and to show that the attached coatings were merely conductors to the charge. At present it is usual to fit open jars with sets of moveable coatings of common tin plate; but the most complete method is to employ a small glass sphere with a long neck, nicely varnished, and give it coatings of dry mercury, which is easily managed.[1]

67. In these experiments we have supposed the jar to be charged positively, that is, from the positive conductor P, fig. 28 (44), the outer coating A, fig. 32, being connected with the ground: now if we charge the jar from the negative conductor N, fig. 28, and connect the positive conductor P with the earth (45), then, according to the Franklinian theory, that will be the same thing as throwing electricity upon the outer coating instead of the inner, as in the former case, since by the theory, what we take away from one side we add to the other (65); it is, in fact, the converse of Exp. 28 (66), supposing the jar, fig. 35, to be reverted upon the charging rod and charged upon the opposite coating (62). That such is really the case may be shown by carrying out the following experiments.

Exp. 32. Charge the jar A, fig. 32 (60), negatively (63), that is, by exposing its charging rod and ball *a* to the negative conductor N, fig. 28 (44), the outer coating A and positive conductor P of the machine being connected with the earth. When charged, place the jar on an insulated stand, as in fig. 35, take off the surplus spark (62), and test the charge of the jar by an electroscope such as represented fig. 7 (17); the outer coating will be found positive.

Exp. 33. Charge the jar by reverting it as before described (62), and repeat the former examination of its electrical state, the same result will be obtained.

These experiments may be further varied by charging under similar conditions: first, from the positive conductor P of

[1] Philosophical Transactions for 1836, p. 441

the machine (44); secondly, from the negative conductor N, the same result will be always obtained.

According to the Franklinian hypothesis, then, the charging of a jar from the negative conductor is the same thing as throwing positive electricity upon the outer coating (67); and this may be accomplished, either by placing the jar on an insulator, as in fig. 35, and connecting the charging rod *p* with the negative conductor N, and the outer coating *n* with the positive conductor P, or otherwise, by reverting or turning the jar over, so as to rest on the charging rod, and then throwing electricity on the outer coating directly.

68. It is further evident according to the Franklinian hypothesis, that an electrical jar always becomes charged by what may be considered as the transfer of its own electricity, as exemplified by the arrangement and the mode of charging in Experiment 28 (66), in which one side of the jar is exposed to the positive conductor P and the opposite side to the negative conductor N, no matter which, all connection with the earth being removed. The result therefore is virtually the same in the ordinary method of charging, since one of the coatings will be always in communication with the opposite conductor of the machine through the table and ground or other conducting support on which the jar is placed; the machine being arranged in the manner already described (45).

The following experiment is conclusive of this fact.

Exp. 34. Place an electrical jar on an insulated support as in the previous arrangement, fig. 35 (66), expose the ball *p* of the charging rod to the action of the positive conductor P of the machine fig. 28 (44), and let the negative conductor N be perfectly insulated; set the machine in motion, and little or no charge will accumulate in the jar; connect the outer coating *n* of the jar with the ground, still the jar will not be charged so long as the negative conductor of the machine remains insulated. Connect the negative conductor N with the ground, but disconnect the jar from the ground so as to leave the jar

insulated, still the jar will not charge; connect now the negative conductor with the outer coating of the jar, either directly or through the circuit formed by the connection of both with the earth, the charge then immediately proceeds. These results are conclusive of the fact that a coated jar always charges by the transfer of its own electricity, since no charge accumulates when from any circumstance both conductors of the machine cannot operate together on the opposite surfaces of the glass: the charge is therefore essentially a new distribution of the electricity already present in the jar, effected through the agency of the rubber, the glass, and the conductors of the electrical machine.

69. This elementary principle of electrical action is not without much practical value, inasmuch as it enables us to divide a given accumulation into any number of equal parts. If, for example, we place near each other on a freely conducting base, two equal and similar jars, one charged with a certain quantity of electricity, the other uncharged, and connect the charging rods of these two jars by an insulated metallic rod, fig. 33 (61), one-half the electricity of the charged jar will pass over to the uncharged jar, so that each jar will contain one-half the original charge. If we place a third jar uncharged by the side of one of the former jars, and treat these as in the former case, we shall have then in each jar one-fourth of the original charge. If we share the charge between three equal jars, we may obtain one-third the original charge, and so on. The ball of the charged jar is, in fact, as respects the uncharged jar, equivalent to the positive conductor of the electrical machine; and the outer coating equivalent to the negative conductor, so that as much electricity tends to run off as the charged jar can yield up and the neutral jar receive, which, if the jars be precisely alike in all respects, will be one-half, one-third, &c. the quantity, according to the number of jars employed in the experiment. The electricity which thus tends to pass off upon the inner coating of the uncharged jar, causes, on the principle just stated, a similar

quantity to leave the outer coating, which quantity passing to the outer coating of the originally charged jar supplies on the same principle the addition requisite to the flow of electricity from the rod communicating with the inner coating,—thus further proving that we cannot add to or abstract electricity from one side of an electrical jar, without at the same time abstracting from or adding an equal quantity to the other.

70. Some confusion has not unfrequently arisen in all these experiments for want of a clear conception of the electrical conditions of the jar, and the relative position of its inner and outer coatings, which really in no sense virtually differ: all complication will immediately vanish in referring the experiments to a simple plate of coated glass, fig. 34 (64): here, as is evident, there is no inner and outer coating, and it is quite immaterial which surface we electrify from the positive or negative conductor. We may also further remark, that although in charging coated glass from the positive conductor, we assume, by the Franklinian hypothesis, a communication of redundant electricity to either side whilst in charging it from the negative conductor, we assume, on the contrary, an abstraction of electricity from either side; yet it is quite impossible to determine which is really the positive and which the negative excitation, and hence it is only by a convenient and arbitrary assumption we refer positive electricity to the excited glass, and minus or negative electricity to the rubber (15). We might, however, as easily imagine the reverse of this, and attribute the redundant electricity to the rubber on the same hypothesis, for any thing we know to the contrary. If we merely consider these opposite states in the light of two absolute forces, which they virtually are, we avoid such arbitrary assumptions, and we have a view of electrical action sufficiently theoretical for a fair exposition of the phenomenon, and sufficiently practical for experimental investigation.

71. Having considered how the hypothesis of Franklin applies to the elucidation of the Leyden experiment, it will be requisite to explain, briefly, the application of the doctrine

of two independent fluids (32) (37) to similar phenomena. According to this doctrine, the Leyden experiment consists in a separation of the two electricities resident in the glass, and a transfer of each to its opposite surfaces. Let, for example, the jar be arranged as in fig. 35 (66), with its charging rod exposed to the prime conductor, and its outer coating to the negative conductor of the machine. In this case the vitreous or positive electricity of the outer surface being repelled by the vitreous electricity thrown on the inner surface of the glass, and attracted by the resinous electricity of the rubber, is disengaged and abstracted from the outer coating, leaving the external surface of the glass charged with resinous electricity. In the same way, the resinous electricity of the inner coating being repelled by the resinous electricity now in excess on the outer coating, and attracted by the vitreous electricity of the machine, is also disengaged and abstracted; and thus one surface of the jar becomes charged with vitreous electricity, and the opposite surface with negative electricity. The two electricities of the jar are disunited in the greatest possible degree by the respective actions of the excited rubber and glass of the machine, and will tend to recombine with a force varying in some direct ratio of the amount of disturbance, and in some inverse ratio of the thickness of the intervening glass by which they are separated. It is this which constitutes the charge as exemplified in the Leyden experiment.

72. Before any conducting communication is established in a charged jar between the interior and exterior surfaces, the tendency of the opposite elements to combine will be exerted in the direction of the intervening glass, and will by their mutual attraction approach as nearly to each other as the resisting intervening electric particles will permit: hence, on removing the coatings, as in Experiment 31 (66), we find the disunited electricities adhering strongly to the surface of the glass under the coating. When, however, we complete a conducting communication between the coatings, and annihilate,

as it were, all distance or resistance to the re-union of the two elements, then they re-combine, and the jar is said to be on this hypothesis discharged. If the re-union takes place through the glass itself, which is sometimes the case, then a fracture of the jar ensues of a very striking and peculiar character.

73. Since the process of charging consists in collecting, by means of the electrical machine, all the vitreous or positive electricity of the jar upon one surface, and all the resinous or negative electricity upon the other, it follows that unless we can bring the machine to act upon both sides of the jar, we cannot obtain a charge: it is requisite, therefore, to establish a communication between each side of the jar and the two conductors of the machine, either directly, as in Exp. 28 (66), or through the medium of the ground: hence it is on this hypothesis that an insulated jar refuses to charge, and that we cannot abstract either of the electricities from one side without at the same time abstracting an equal quantity of the opposite electricity from the other, as may be illustrated by all the preceding experiments, and by the general series of experiments resorted to by Franklin.

74. Although these inquiries show that the solid electric intermediate between the coatings is the means of confining the two electricities to the opposite surfaces of the jar, yet they throw no light on the actual electrical condition of the interior particles of the glass. The beautiful and comparatively recent experiments, however, of Faraday, go far to elucidate this important question. According to this philosopher, the particles intermediate between opposite electrical powers become, as before explained, fig. 20 (38), placed in a constrained or forced state; the particles assuming positive and negative points which are symmetrically arranged with respect to each other, as roughly represented in fig. 20. This succession of positive and negative powers, exerted as it were in lines between the two limiting coatings, he further shows is accompanied by a repulsive or

diverging force in a transverse direction. Now when this condition, termed *induction*, is permanent, then we have perfect *insulation;* but directly the particles begin to discharge into each other, then more or less of conductibility ensues, and no charge accumulates. If, on the contrary, the transverse action is greater than the particles can support without discharge, then the whole series is, as it were, mechanically deranged or broken up, constituting what he terms 'disruptive discharge,' as in the case of a fracture of a charged electric jar by the power of the two electric forces operating on each other by induction, through its substance, and which is characterized by a peculiar rupture of the glass, a portion of which is reduced occasionally to a fine powder. Hence it is that an interval of air is quite unable to sustain any considerable electrical accumulation as compared with solid electric matter. Faraday has characterized any insulating medium—solid, fluid, or gaseous, through or across which the inductive electric forces act—by the term 'dielectric.'

75. According to these views, not only would the opposite electricities be found adhering to the glass beneath the coatings, as in Exp. 31 (66), but they would have penetrated also into its substance to a greater or less extent, causing a sort of surcharge or residuum after what appears to be a complete discharge of the whole system; and this is really the case.

Exp. 35. Let the middle of a circular plate of crown glass, about 8 inches in diameter, be placed between two similar discs of gilt wood of about 5 inches in diameter, and about the $\frac{1}{4}$th of an inch in thickness: affix a light glass handle to one of these discs in the way shown in fig. 31 (53), and insulate the whole system upon a slender glass rod, after the way represented in fig. 34. We have then a coated pane with moveable coatings: charge this system by making a temporary communication between the inferior coating and the ground, and throwing electricity on the upper surface: next remove the connection with the ground, and discharge the system with

the discharging rod, fig. 33 (61). To all appearance the electrical disturbance has vanished. If, however, we endeavour to detach the upper coating by its insulating handle, an adhesion will frequently arise between the glass and the coating, strong enough to lift the whole mass; and if a little time be given, a residuum or return charge is found to occur, sufficient to cause a small second discharge on the application of the charging rod. Faraday, by means of coated lac, observed this return charge after a lapse of ten minutes, and considers it due to the electricity coming forth as it were from the lac, into which it had penetrated in consequence of the forced electrical condition into which the particles had been previously brought.

Exp. 36. Complete the discharge as before: remove the upper coating, and subsequently the glass, from off the inferior coating, by carefully lifting it by one point of the edge, so as not to disturb its electrical condition: test the state of the coatings by an electroscope, and it will be found, on the principle of the electrophorus (53), that the upper coating, originally positive, will now appear negative; and the under coating, originally negative, will be positive, showing evidently the still excited state of the particles of the dielectric.

Exp. 37. Deprive the two coatings of all electricity, and replace the system as before, having been careful to preserve the insulated state of the glass plate: complete five or six alternate contacts with the coatings and the finger: first touching one and then the other, a weak spark will be commonly elicited, and if the discharging rod be applied, the system may be again discharged, although in a low degree. As the coatings were rendered perfectly neutral, this subsequent charge could only have arisen from the dielectric particles, much in the way explained by Faraday (22).

THE ELECTRICAL BATTERY.

76. When several coated jars are united electrically by joining together all their charging rods or inner coatings, and placing them on a common conducting base, so as to unite in a

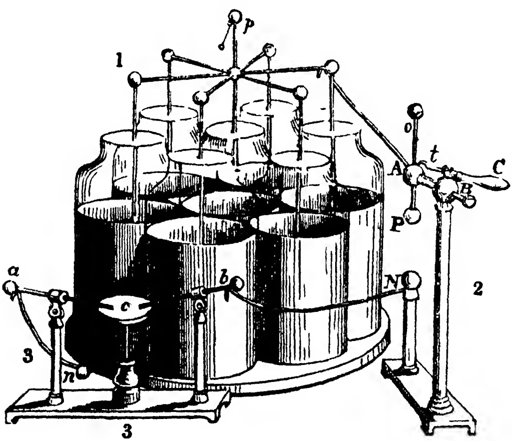
similar way all the outer coatings, as represented in the next figure 37, such a combination is termed an *electrical battery*. When charged from a common source, and discharged in the usual way, they all act together in mass, as one great jar; we have hence a means of multiplying electrical accumulation to an almost unlimited degree, provided we can obtain a sufficient charging power. The resulting effect, although not quite in the ratio of the number of jars in combination, on account of the obstructions of the charging rods, &c., will still have a fair approximation to it if the charging power be high and the jars be of sufficient magnitude. With a battery of 100 jars, each about 13 inches in diameter, 2 feet high, and exposing each about $5\frac{1}{2}$ square feet of coated glass, the Dutch Electrician, Van Marum, obtained a tremendous action. When this battery, exposing altogether 550 square feet of coated glass, and charged by the great Teylerian machine (48), was discharged through and upon various kinds of matter, its force was quite irresistible. When passed through steel bars 9 inches in length, $\frac{1}{2}$ inch wide, and $\frac{1}{12}$th thick, the bars became powerfully magnetic: a piece of box-wood, 4 inches in diameter and 4 inches long, was rent in pieces: various metallic substances were melted and dispersed in all directions: an iron wire, 25 feet in length, and about the $\frac{1}{140}$th part of an inch in diameter, fell under the shock into red-hot balls thrown in all directions: a piece of tin wire, 8 inches long and $\frac{1}{18}$th of an inch in diameter, disappeared in a cloud of blue smoke, from which fell red-hot globules of tin;—these repeatedly bounded from a piece of paper beneath.

77. In the construction of such batteries it has been usual to fit them up in series of small jars, each jar having a separate cover of mahogany, with an attached charging rod and chain. They are placed in partitions, in a case lined with tin-foil, and the jars are connected by cross brass rods terminating in balls. The expense of all this is very great; and moreover such an arrangement is undesirable. The most effective arrangement is to employ jars of as large dimensions as possible, prepared as

already explained (60). The fewer jars in a battery the better. They should be grouped on an open conducting base about a central jar, as in No. 1 of the next figure (37), either in groups of five, seven, or any other convenient number. If the battery requires further extension, then unite such groups by joining the charging rods of their central jars. In this way, by the aid of a few common brass wires, and some holes in the charging rods, we may put together in a short time a battery of any required power and of the most efficient description, with very little inconvenience, trouble, or expense.

78. The management of electrical batteries requires very considerable caution. They can be, of course, easily charged by connecting the central rod with the machine; the charge will then pervade the whole through each conducting ramification. To discharge such a series it will be desirable to employ two insulated balls, one in communication with the central charging rod, and the other with the common conducting base

Fig. 37.



on which the jars are placed, that is to say, with the external coatings, and which balls can be joined at any required instant, as shown in No. 2 of figure 37. In this figure, A is a ball of

brass supported on a rod of varnished glass A B by a glass pillar and mahogany ball B. The ball A has a vertical hole through its centre, so as to admit of a short brass rod P *o*, carrying a discharging ball P, falling freely through it. The rod P *o* has two or more small holes drilled in it, by which it can be supported at a given height on the ball A, by means of a pointed bent wire attached to a hinge joint at *t*, and a glass handle *t* C. The front of the ball A receives a direct metallic communication, *p* A, with the battery, as shown in the figure. Immediately under the discharging ball P is a similar ball N, fixed on a stout pillar of glass, and connected in any required way with the exterior coatings or base of the battery. When the operator requires to discharge the battery through any given circuit, he liberates the bent brass wire support fixed to the joint at *t* by a light touch of the glass handle C. The ball P then falls on the ball N, the balls P N come together, and the battery discharges without danger to the operator, and always in the same way.

79. When certain substances are exposed to the action of the battery, they are placed on an insulating table between two directing wires, which may be adjusted conveniently for the particular experiment. An instrument of this kind is termed a 'Universal Discharger,' and is represented in No. 3 of figure 37. The two directing rods *a b* are fixed on pillars of glass, and are so arranged as to slide through short spring tubes fixed to the joints, and move in any direction; the insulating table *c* is placed between these rods, and is fixed on a glass rod, supported in a socket of wood so as to slide with friction in a piece of compressed cork, up and down, and be maintained to any required height: the substance to be operated on is to be placed between the directing rods *a b* on the table *c*, or stretched between them: one of the rods is then connected with the lower insulated ball N of the battery discharger, and the other with the common conducting base on which the battery rests, as shown in the annexed figure 37, in which it is evident that directly we liberate the ball P, and cause it to fall on the ball

N, we have completed a circuit *p* A P N *b a*, immediately through the substance exposed to the battery, and extending directly from the inner to the outer coatings.

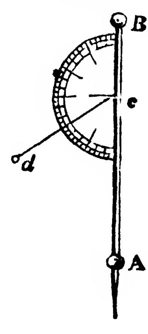
It may be proper to observe that several contrivances have been employed for discharging electrical batteries; but that just described is very safe and efficient.

ELECTROMETERS.

80. An electroscope adapted to the measurement of electrical quantities of any kind is termed an *Electrometer*, and is employed to determine either the relative quantity of electricity actually in operation,—its attractive or repulsive force under given conditions,—or the comparative effect produced by its discharge in various ways. The different electroscopes already described (41) are converted into electrometers by applying to them some graduated measure of their respective indications. The following may be considered as being amongst the most perfect and available of such instruments.

81. *Quadrant Electrometer*.—This electrometer was invented by Mr. W. Henley, F.R.S., so long since as the year 1772. It has been much employed in certain electrical investigations, especially with the electrical jar, or battery, and appears to be the first instrument of this kind ever used. A short reed *c d*, fig. 38, terminating in a light ball of pith *d*, is set on a delicate axis attached to a vertical conducting rod or stem A B. This axis *c* is in the centre of a graduated quadrant or semicircle, also affixed to the same stem. The stem has a ball at A, against which the reed *c d* reposes when not electrified.

Fig. 38.

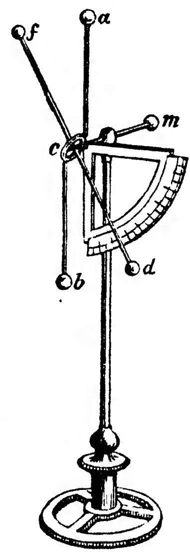


When charged either by placing the instrument on one of the conductors of the machine, or on the rod of an electrical jar, as in fig. 37, the reed *c d* rises into the air, and marks, as an index, on the graduated semicircle the angle of divergence by

which the comparative amount of electrification or charge may in some cases be estimated.

82. *Quadrant Electrometer of Double Repulsion.*—This instrument, constructed on the same principle as the former, is represented in the annexed figure 39. A small elliptical metallic ring *c* is set obliquely on a short brass rod *c m*, sustained on an insulated support: two light metallic wires, *c a*, *c b*, are fixed vertically at the opposite ends of the long diameter of the ring; and these wires terminate in gilt balls of pith or cork. In the direction of the short diameter of the ring, a delicate axis is set on points which by a central transverse pin carries two light reeds *c d*, *c f*, forming together one long index *d f*. This index also terminates in gilt pith balls: when uncharged, the index reposes against the vertical wires *c a*, *c b*: when electrified, either alone, or by connecting the rod *c m* with a charged conductor or jar, the index is repelled in opposite directions, above at *a*, and below at *b*, by a double repulsion, the amount of divergence being estimated by a graduated quadrant fixed in the centre of the axis of the index, behind the elliptical ring *c*. The tendency of the index to a vertical position is regulated by short pieces of reed, placed on the opposite arms of the index, and which slide with friction on them, so as to admit of being placed at various distances from the centre: thus the index diverges with an extremely small force.

Fig. 39.



83. This class of electrometer, although convenient and useful in many instances, is nevertheless of very limited application in others. We are certainly enabled to say that, *cæteris paribus*, when the angular divergence is the same, the same quantity of electricity is in operation: with a greater diver-

gence, there is a greater quantity,—with a less divergence, less; but how much greater or less it is not easy to determine, since we have with the divergence to take into the account the diminishing force of repulsion as the distance increases, and the simultaneous increasing force of gravity at different angles, together with all the different and varying distances from the centre to the extremities of the repelling arms; and also the variable oblique action of the forces as the index rises; all of which is to a certain extent indeterminate. The common Henley's Quadrant Electrometer, when placed on a charging jar, as in fig. 37 (78), exhibits at first little or no activity. As the charge proceeds, its action rapidly increases: finally, after arriving at an angle of about 60 degrees, the rate of progress of the index is slow, and it will frequently attain a maximum elevation before the charge is complete. Cavendish states in his manuscripts, that when this electrometer is considerably elevated on a long stem above the charged conductor on which it is usually placed, the indications will be different from those obtained when it is situated close upon it. In the first case, the electrometer is more sensible at the beginning of the motion; in the latter case it is less sensible. The difference by experiment with similar quantities of electricity was found to be considerable: thus when close upon the conductor, the divergence was only 5 degrees; when elevated, the divergence amounted to 21 degrees. On the other hand, towards the close of the motion, the sensibility of increase was found to be less in the elevated than in the close situation. The safest method perhaps is to determine experimentally for each particular instrument the angular quantity corresponding to a given charge, and to estimate accordingly.

84. The following are the results of some experiments of this kind with the electrometer of double repulsion (82) when connected with an electrical jar, the quantity of electricity being estimated by the number of revolutions of the machine, or by other known units of measure to be presently described (90).

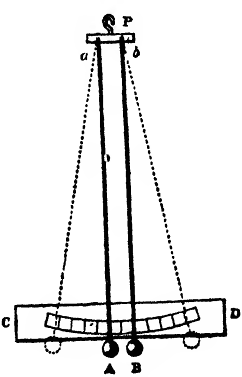
Measures of Electricity.	10	20	30	40	50	60	70	80	90	100
Degrees of Divergence.	1	5	12	16	20	28	30	34	36	40

If we reject the first two experiments, and commence with 30 measures, we find the angular divergence of the index nearly as the quantity of electricity: thus the divergence corresponding to the quantities 30, 60, and 90, which are as the numbers 1, 2, 3, is 12, 28, 36, also as the numbers 1, 2, 3, or nearly so; and this law appears to obtain generally within certain limits. Thus the quantities 50 and 100 give the divergences 20 and 40, which are both as 1 : 2.

Achard states, that to estimate truly the repulsive force by Henley's electrometer, the graduations should be according to a scale of arcs, the tangents of which are in arithmetical progression. The truth of this, however, can only be ascertained experimentally.

85. *Cavendish's Electrometer.*—This instrument, represented in the annexed fig. 40, is a most ingenious and ready conversion of the double reed electroscope, fig. 24 (41), to an instrument of measure. The following description of it is extracted from the valuable manuscripts of this distinguished philosopher. *a* A and *b* B are two 'wheaten straws,' each 11 inches long, supported by fine steel pins resting on notches in a small metallic plate P, so as to turn on each of these points as a centre. The straws are left open below, and carry two small cork balls A B, about one-third of an inch in diameter, covering their open ends. In order to increase the force with

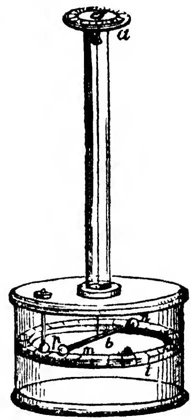
Fig. 40.



which the straws tend to close at any angle of divergence, the lower open ends are occasionally loaded with short pieces of wire of a given weight. Now it is not difficult to find, on common mechanical principles, the relative forces with which the straws, considered as levers, will tend to the perpendicular when light, and when loaded with given weights, and thus estimate the relative repulsive power required to maintain the same angle of divergence in these two cases. Suppose, for example, the force tending to the perpendicular from a given angle of divergence was four times greater when loaded than when light, we might infer that if divergent by electrical repulsion, four times the repulsive force must be exerted to sustain the loaded reeds at the same angle as the light reeds. Supposing the force of gravity in this kind of instrument to be concentrated in the balls themselves, "the force required to separate them will be as their weights directly;" so that by a careful manipulation we may, with this kind of instrument, measure the repulsive force pretty accurately. In applying this electrometer, we suspend it from the charged body, and at a distance of about 6 inches before a strongly marked paste-board scale *c d*, the eye being situated about 30 inches before the scale, so that by means of an eye-piece the angle of divergence is easily estimated. The straws *a* A, *b* B reach nearly to the bottom of the cork balls, but not quite, so that the lower ends of the small wires with which the reeds are loaded may be just even with the surface of the ball, being retained in their places by a little soft wax.

86. *The Balance of Torsion.*—M. Coulomb, a distinguished member of the Royal Academy of Sciences at Paris, describes, in a memoir presented to the Academy in the year 1785, a method of balancing the force of electrical repulsion against the re-active force of a fine wire, suspended vertically, and twisted more or less from its quiescent position. This has been termed *Coulomb's Torsion Balance*. It is represented in the annexed figure 41. A fine wire or silver thread *a b* is attached to a rigid pin at *a*, and carries at its lower extremity *b*

Fig. 41.



a small weight, and a transverse arm or lever *m n*: a small gilt disc of paper or a gilt pith ball, insulated on a thread of lac, is attached to one end *m* of this arm, and a paper vane, to arrest the oscillations, is fixed to the other extremity: the whole is enclosed in a case of glass. Immediately next the ball *m* there is another similar ball *p*, insulated and supported by the cover of the glass case: the centre of this ball corresponds with the zero of a graduated circle *p t n*, surrounding the cylindrical case, by which means any angular distance between the balls *p m* can be estimated. When the ball *p* is electrified, or charged, and placed in the case through a hole in the cover, so as to touch the ball *m* of the lever, then the balls repel each other (16); the lever *m n* is turned upon its centre, and the suspensory wire becomes more or less twisted: in this way a re-active force is produced, and a balance obtained to the electrical repulsion at a given point.

Let, for example, a charge be communicated to the fixed ball *p*, such as would cause the two balls to separate 36 degrees; then, as is evident, the wire would become twisted through an angle of 36 degrees; and since Coulomb proved that its re-active force, or tendency to return to its previous state, was exactly proportionate to the torsion, 36 degrees becomes the measure of the electrical force operating between the balls at that distance.

Suppose it be now required to find the torsion force required to maintain the balls against the electrical force at a divergence of 18 degrees, or one-half of the former angle; we then turn the central pin at *a*, to which the wire is fixed, in opposition to the direction of the repulsive force, until we oblige the balls to rest at the given angle: this is the new force of torsion.

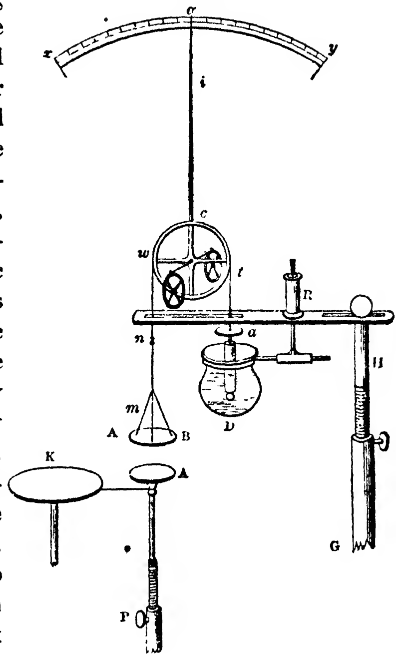
For the measurement of this, there is a graduated circle and index, with a milled head at the termination of the suspension pin *a*. Suppose, for example, that in order to maintain the balls at 18° we had twisted back the wire *a b* against the electrical force 126°, as measured by the graduated circle at *a*, then 126°, together with the former torsion of 18° = 144°, would be the total force at that angle, and we should have the numbers 36 and 144 for the relative values of the repulsive forces at the angular distances of 36° and 18°.

87. *The Bifilar Balance.*—In this electrometer, invented by the author and described in the 'Transactions of the Royal Society' for 1836, a re-active force is obtained by means of a lever at the extremity of two parallel and vertical threads of unspun silk, suspended within a quarter of an inch of each other from a fixed point: the threads are stretched more or less by a small weight, and the repulsive force is caused to operate much in the same way as in Coulomb's Balance of Torsion. As the threads tend to turn, as it were, upon each other, the stretching weight becomes raised by a small quantity, and thus gravity is brought to re-act against the repulsive force in operation. The delicacy of this balance is extremely great, and will render sensible a force of the $\frac{1}{50000}$th part of a grain.

88. *The Hydrostatic Electrometer.* — In this instrument, the essential parts of which are represented in figure 42, the force of electricity is balanced against the position of a small counterpoise, partially immersed in water. A light circular gilt disc A is fixed on an insulating rod at the extremity of a graduated slide, by which it may be raised or depressed to any required distance: opposed, and directly over this, is a similar gilt disc B, insulated by a suspensory silk thread *n m*, and attached to a silver thread *c w n* passing over a quarter of the circumference of a wheel *w*, set on light friction wheels, in order to obtain a free motion. The weight of the conductor B is counterpoised by a short cylinder of wood *a*, suspended

in a similar way from a silk line *t a* passing round the opposite side of the wheel, and partly floating in water contained in a small glass vessel D: the wheel carries an index of light reed *c i*, moveable over a graduated arc *x o y*: the centre *o* of this arc is marked zero. The counterpoise *a* may be so adjusted, either by small weights, or by a regulating screw R, by which the glass vessel D, containing the water, is supported, that when in equilibrio at a certain immersion of the float, the index *ci* is at zero of the scale.

Fig. 42.



The whole of the wheel-work, with its arc and other attached parts, may be raised or lowered through measurable spaces by means of a rack and pinion C, fixed in the column of support G H. The details of the framework of the instrument are omitted in the figure, in order to avoid complication.

It follows from this arrangement, that so soon as any new force is brought to operate on either side, suppose the force of a few grains' weight, then the cylindrical float D either sinks or rises in the water, until the fluid which it continues or ceases to displace balances the weight added; and this is shown by the position of the index on the arc *x o y*; so that any force operating between the circular discs A B may be referred to a

known standard of weight determined experimentally in terms of the divisions of the arc *x y*.

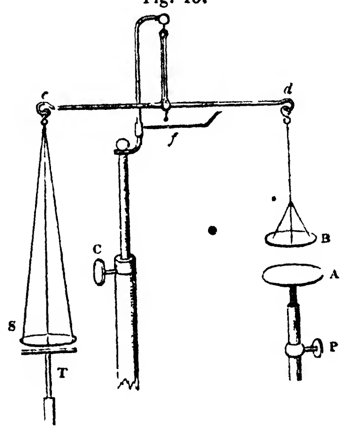
In the application of this instrument to the measurement of electrical attraction, the suspended disc B is connected with its silver thread of suspension *c n* by a very fine wire, and a charge is communicated to the fixed disc A. For repulsive forces we remove the connecting wire, so as to leave the disc completely insulated; we then charge it with a similar electricity to that of the disc A, either by bringing the discs in contact or by other insulating temporary communication, or by a separate and temporary charge. In either case the forces are shown on the arc *x y* either in direction *o x* or *o y*.

To estimate the distance of action A B, the two discs are first made to touch and lie evenly on each other; they are then separated by a given measured space, either by means of the rack at C or the rack at P: this will be the distance at which the force begins to operate. The final distance, when the balance is obtained, will be this distance plus or minus the quantity which the disc B has either ascended or descended; and which is so arranged that a vertical motion of B of the 100th of an inch moves the index *c i* exactly one degree of the arc. Thus, suppose the first distance A B being regulated to one inch, an attractive force had caused B to descend until the index had reached 10 degrees, at which point the force became balanced, then the actual distance of action would be 1 inch + $\frac{1}{10} = \frac{11}{10}$ths, taking $\frac{1}{10}$th as the unit of measure. Or supposing we required to determine the force of a given or variable quantity of electricity at a constant or variable distance, previously determined as before, we have only to bring the index to the zero of the arc by means of the screw at R which regulates the water-vessel, which must be done while the instrument is under the operation of the electrical force, and we thus restore the measured distance. If we now discharge the electricity of the attracting or repelling discs A B, the index will move either toward *x* or *y*, as the case may be, and mark off in degrees the relative amount of the respective forces.

The quantity of electricity, all other things being the same, will be, by a law of electrical charge to be presently explained, as the square roots of the forces as expressed by the index. Thus, if in any two consecutive experiments the forces were 4 degrees and 9 degrees, then the relative quantities of electricity in operation will be as $\sqrt{4} : \sqrt{9}$, that is, as $2 : 3$. A more particular description of this electrometer will be found in the Transactions of the Royal Society for 1839 and 1834.

89. *The Scale-beam Electrometer.*—The common scale-beam furnishes an exact measure of electrical force, and has been applied to the purposes of an electrometer with considerable effect: the particular arrangements are described by the author in the Transactions of the Royal Society for 1834; they are very similar to those of the electrometer just described, with this exception, that a common balance is substituted for the wheel-work, the suspended disc is counterpoised, and the force of the attraction is estimated by weights placed in the scale-pan. The general arrangement is shown in figure 43, in which A B are the opposed discs; *c d* a delicate beam sustained on a column of support C, furnished with a rack and pinion as at C in the preceding instrument; S is a scale-pan resting on a small table T, and *f* a light arm to be occasionally turned in under the beam, either to support it or prevent it from descending beyond a given point.

Fig. 43.



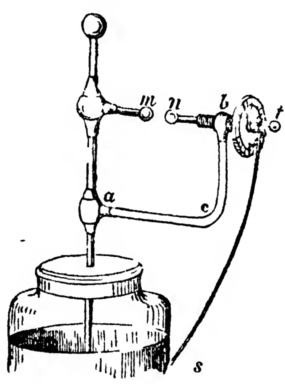
Electricity is communicated to the disc A through the insulated conductor P, and the attractive force is estimated by small weights in the pan S.

90. Electrometers more especially applicable to the Leyden

jar, in combination with the preceding, are of great moment in electrical investigations; particularly those by which a precise estimate of the quantity of accumulated electricity may be attained: several methods have been resorted to for the construction of such instruments, including the principle of the fusion of metallic wires by the subsequent discharge. Of such instruments, the most available are the electrometers of Lane and Cuthbertson; the Unit measure and Quantity jar; and the Thermo-electrometer.

91. *Discharging Electrometer.*—This electrometer was contrived about the year 1767, by Mr. Thomas Lane, a medical practitioner, of London, his object being to obtain from an electrical jar repeated discharges of a given force. The instrument consists of a bent arm of glass *a c b*, fig. 44, attached to the charging rod *a*: this arm sustains a screw-slide and tube carrying a rod and ball *n t*, connected with the outer coating of the jar by a wire *s*, the ball *n* being, by means of a graduated circle and index at *t*, set at a measured distance from a similar ball *m*, projecting from the charging rod. When the increasing force is sufficiently powerful, an explosive or disruptive discharge ensues between the balls *m n*, and it is demonstrable that the relative quantity of electricity accumulated at the instant of the discharge is directly as the distance between the points of contact of the balls: thus, when the discharge takes place at a distance of four-tenths of an inch, the quantity of electricity accumulated would be double that producing a discharge at two-tenths of an inch, and so on, as will be presently demonstrated.

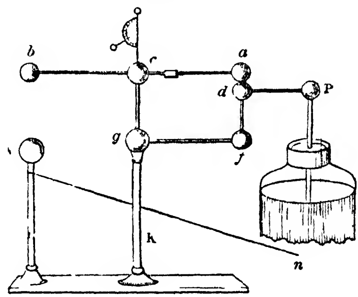
Fig. 44.



92. *Cuthbertson's Discharging Electrometer.*—This instru-

ment, represented in the annexed figure 45, consists of an insulated metallic rod *a b*, set on a knife-edge centre at *c*, and equally balanced by a hollow brass ball *a b* at each end. The centre is covered by a ball *c*, with slits in it to allow of the motion of the arms of the balance. One of these balls, *a*, rests on a second similar ball *d*, sustained from the insulator K of the balanced arm *a c b*, and to be connected when the instrument is applied with the positive ball P of a jar or battery. Immediately under the opposite ball *b* is a similar ball N, but fixed at a distance from the ball *b*: this last ball N is connected with the negative side of the jar or battery. The arm *c a* is divided into 60 parts, after the manner of a common steelyard, to which a loose slider is adapted, which being set to different divisions from the centre *c*, furnishes different measured resistances to the motion of the rod *a b*, about the centre *c*,—estimated in grains. These arrangements being complete, suppose the slider set at 10 grains, then, as the charge proceeds, the balls *a d* will begin to repel each other (16). When the force just exceeds the resistance, the arm *c a* will rise, and the slider, which is loose upon the arm, will fall towards the centre *c*: then the arm *c b* will descend, and the ball *b* coming within the limits of the attractive force between N and *b*, will rapidly approach the ball N, and discharge the battery by the circuit P *d f g c b* N *n*.

Fig. 45.



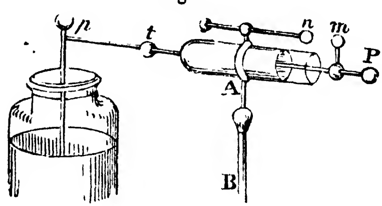
It has been usually supposed that the accumulation will be as the resistance directly, so that when the slider is set to 5 and 10 grains, the respective quantities of electricity accumulated and discharged will be as 1 : 2. Such, however, is not the case, as we shall presently see. To obtain a double charge, the

slider must be set to 20 grains, or four times the first resistance,—the electrical force being as the square of the quantity of electricity accumulated (112). Henley's Quadrant Electrometer is usually placed in the centre of this discharger, by which means, as was observed by Cuthbertson, we unite into one instrument, Henley's Electrometer, by which we see the progress of the charge (82); Lane's Discharging Electrometer, by which the battery is discharged when the balls *b* N come within a striking distance; and obtain a measure of the repulsive power in weight, and hence a measure of the quantity of the electricity accumulated.

If we connect the centre ball *c* with the positive conductor P, and place N without the striking distance from *b*, we may then take *d* as a mere insulated support, and allow the balls *b* N to close by attraction. In this case the ball *d* may be insulated on a plain glass rod. This instrument, as is evident, may be applied in various ways; the latter, however, is perhaps the best.

93. *The Unit Measure.*—This species of electrometer, for the measurement of quantities of electricity, was invented by the author in 1829, and described by him in the Phil. Trans. for 1834, page 217. It consists of a small Leyden phial, A, fig. 46, about five inches in length, and three-fourths of an inch in diameter, fixed horizontally on a long insulator B, and interposed between the machine and the jar or battery to be charged: this small phial is coated to within nearly two inches of the top,

Fig. 46.

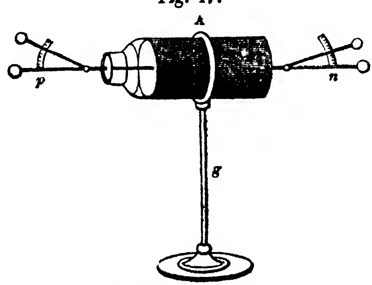


so as to expose about six square inches of coated glass; the charging rod is connected at P with the charging conductor of the electrical machine, and the outer coating with the jar or battery by a rod *t p*. When the machine is set in motion, this small jar begins to charge, and by the law of the Leyden

phial (65), as much electricity as is thrown upon the inner coating by the electrical machine, leaves the outer coating to be distributed over the inner surface of the jar. When the accumulation in the phial A has reached a certain height, as measured by two small balls *m n*, connected with the inner and outer coatings on the principle of Lane's electrometer, just described, a disruptive discharge or explosion ensues, which marks a certain quantity of electricity received as a charge by the battery in terms of the small jar, charged to a given degree: this explosion, for all practical purposes, sufficiently discharges the phial, and places it in a state to mark a similar quantity, at each instant of the explosion, as the charge proceeds: thus the small jar becomes a sort of unit of measure, showing how many phials of electricity have, as it were, been poured into the charged jar or battery: it is only requisite to fix the distance between the exploding balls *m n*, by means of a graduated slide on the charging rod, so as to determine the magnitude of this unit, and we assign precisely its comparative relative value.

94. *The Quantity Jar.*—The communication of small measurable quantities of electricity to insulated conductors is of great importance to the progress of electrical research. The unit measure last described is not always available to this purpose, which is best effected by what may be termed a Quantity Jar, invented by the author, and prepared as in fig. 47. In this figure A is a coated jar, exposing about a square foot of coated glass: it has a large uncoated interval varnished; it is insulated horizontally on a long varnished glass rod *g*, and in addition to the charging rod and ball *p*, it is furnished with a similar rod and ball *n*, projecting from the outer coating at the base of the jar.

Fig. 47.



Each of the rods *p n* is furnished with a small electrometer *a b*, on Henley's principle, but consisting of a light straw, balanced on a fine axis by a counterpoise ball, and set in an elliptical ring, similar to the method of the electrometer, fig. 39 (82), except that it is placed horizontally, and is a single reed counterpoised by a short arm and ball. Suppose this jar to be charged with any given quantity of electricity as measured by the unit measure just described, it will then furnish to a small insulated transfer plate or sphere, such as represented *c a*, fig. 14 (26), a succession of sparks, which may for all practical purposes be taken as equal to each other, and which may be transferred to any insulated body K, fig. 42 (88), connected with the electrometer. If we require positive electricity, we first touch the ball *n* connected with the outer coating, so as to neutralize any surplus electricity (62), and then apply the transfer sphere to the ball *p*. If we require negative electricity, we then neutralize first the surplus spark of the positive coating by touching the ball *p* (62), and then proceed to apply the insulated sphere to the ball *n*. We may easily determine by means of the electrometers the range within which the transfer sphere will always become charged with the same quantity.

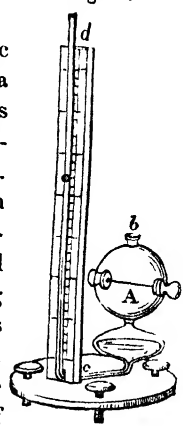
Plates of various sizes and forms may be employed as transfer plates for ordinary purposes: a small disc about 1 inch in diameter will be found convenient. If we require to obtain a double or treble quantity of electricity at once upon the same plate, we must have our transfer plates so proportioned that they shall not only expose double and treble the area, but this area must be placed under twice and three times the extent of linear boundary (114).

In transferring electricity in this way to insulated conductors exposing a large extent of surface, the small transfer disc or sphere may be considered for one or two transfers to have yielded up all the charge after the contact. If the insulated body K, fig. 42 (88), be an open sphere or cylinder, then on contact with the inner surface, all the electricity of the transfer sphere will certainly disappear, as is seen Experiment 21 (26).

In some instances in which we desire to communicate small and equal measures of electricity to a large insulated plane, we may deposit the transfer disc on its surface, and then proceed to a second equal disc; and so on in this way we may insure the communication of successive equal measures: very small jars or plates, exposing from 1 to 4 square inches of coated glass, may be occasionally employed in the transfer of measured quantities of electricity in this way.

We have been rather disposed to dwell on this branch of electrical manipulation, from its great importance in refined inquiries in electricity. Cavendish, as it appears from his manuscripts, estimated electrical quantity much in this way, and in square, globular, or circular inches. By a globular inch he means the quantity of electricity on a globe of 1 inch in diameter, supposing it charged to saturation. Thus, he says, the charge of a circle 18·5 inches in diameter is 13·5 globular inches of electricity; 8 square inches, he says, equals 9 circular inches,—taking the square or circular inch as unity. The quantity jar may be used without the electrometers *p n*, after being charged by the unit jar (93). Its state may be tested from time to time by occasional contact with the double repulsive electrometer (82).

Fig. 48.



95. *The Thermo-Electrometer.* — ' effect of the electrical discharge on metallic bodies is to raise their temperature to a greater or less degree, and in many instances to render metallic wires red-hot, and to dissipate them in a shower of melted globules. The fusion of wire has accordingly been resorted to as a measure of the force and extent of electrical accumulations on coated glass. Independently of this method being uncertain and tedious, it is in many instances quite inapplicable to many refined inquiries. The thermo-electrometer, invented by the author, whilst it avoids all destruction of

the metal, indicates at the same time the comparative heating effect of the discharge, and admits of an accurate estimate of the force in operation. It consists of an air thermometer A *c d*, fig. 48, having a fine wire of platinum passed air-tight across its bulb A, which is screwed also air-tight on a small open vessel containing a coloured liquid, and soldered at the extremity of a bent glass tube A *c d*. The long vertical leg *c d* of this tube is supported by a graduated scale of inches and tenths, on a convenient foot *c*, the lower part of which is marked zero, at the point where the coloured liquid in the short leg finds its level. There is a small screw-valve at *b*, to admit of an opening with the external air, so as to adjust the fluid to zero of the scale.

When an electrical accumulation from a jar or battery is passed through the wire in the ball A, the temperature of the wire is more or less raised, which causes the air to expand and press the coloured fluid up in the long leg *c d*, the altitude being measured on the graduated scale. In this way a comparative numerical value of the heating effect of the discharge may be arrived at; and it is found that the height to which the fluid rises in the leg *c d* is as the square of the quantity of electricity discharged. The delicacy of this electrometer will depend on the size of the platinum wire, which, for ordinary purposes, may be from the $\frac{1}{50}$th to the $\frac{1}{100}$th of an inch in diameter, and about 3 inches in length, corresponding with the diameter of the ball of the thermometer. The electrical discharge is passed through the wire by means of the drop ball, fig. 37, No. 2, the wire being placed in the position of the universal discharger *a c b*, and the circuit N *b c a n* completed by connection with the two balls external to the glass ball A, in which the wire terminates. A more detailed account of this instrument will be found in the 'Philosophical Transactions' for the year 1827, and also in the 'Edinburgh Philosophical Transactions' for 1832.

IV.

LAWS OF ELECTRICAL ACTION.

Actions at a Distance—Views of Faraday—Inductive Force—Law of Electrical Attraction — Repulsive Force — Researches of Coulomb — Laws of Electrical Charge—Investigations of Cavendish—Conditions of Charge on Coated Electrics—Tension and Intensity.

96. The operation of those mysterious and intangible powers in nature, by the agency of which masses of matter influence or act upon each other at very sensible and even very remote distances, is a subject of physical research replete with the most exciting interest, whether we refer such actions to the question of gravity as exerted between the sun and planets at distances of many millions of miles, or to the influences of bodies electrically charged through comparatively insignificant distances of only a few inches. In either case the fact is equally wonderful and important. Philosophers, for a long time unable to assign any sufficient cause in explanation of the action of bodies on each other at a distance, have been content to consider such phenomena in the light of a mere matter of fact—upon which they have been led to rest a theory, without inquiry into the cause.

97. Before entering upon a particular analysis of such actions through the agency of electricity, it may be useful to revert once again to the admirable inquiries of Faraday, inasmuch as they afford a fair view of the nature of the operation by which an electrical force, originating in a certain place, is propagated and sustained at a distance, appearing there, in another place, as a force of a similar kind.

We have already seen, in Exp. 16 (23), that the phenomena of electrical attraction and repulsion are altogether dependent on a preparation principle, termed *induction*, by which a substance is first rendered capable of being attracted or repelled, and is then attracted or repelled. Now this principle

of induction, as we have found, is of the utmost generality in electrical action,—it is the essential function of all electrical development; so that in fact we cannot proceed with any investigation in electricity without some practical knowledge of its nature.

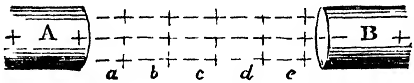
98. According to Faraday (38), the immediate effect of any substance electrically charged is to bring the particles adjacent to it into a peculiar constrained condition, consisting of a new distribution of the electrical forces resident in them, and by which these forces become placed in a new and certain relative position in regard to the electrified substance. These proximate particles, thus electrically affected, now act on the next particles contiguous to them, and these on the next, and so on, through a given series, until the forces throughout the whole become symmetrically arranged in a succession of positive and negative points, as already explained, fig. 20 (38), or, in other words, become *polarized;* thereby propagating the original force to a distance where it appears to be sustained as a force of the same kind, equal in amount, but opposite as to direction, Exp. 14 (21). Now in metallic and other good conducting bodies this polarization of intermediate particles does not subsist for an instant, in consequence of the particles communicating the opposed forces from one to the other, by which the whole condition is lowered; it is, in fact, this act of discharge from particle to particle which constitutes *conduction.* Metallic or other conductors, therefore, will only exhibit the polarized state as a whole; as in the instance of the faces *b c* of the cylinder B, fig. 9 (21). Now this result is altogether independent of the mass of the body, and requires no sensible thickness for its mere development; a piece of the thinnest leaf gold may become positive on one surface, and negative on the other, and that without the least interference of the two electrical forces. Hence all charge will necessarily be found on the surface of conductors (24), since it is only there that the surrounding resisting dielectric medium, capable of sustaining induction, and upon which the charge depends, is found to

commence. If the conductor be hollow, or contain air, still there can be no induction, on account of the opposing actions in all directions from the interior surface of the charged body (24). In the case of electric substances forming dielectric media, as in the instance of the intermediate air or glass between limiting conducting planes, fig. 27 (42), the thickness of the stratum has a most important influence. In such media the forces cannot discharge, as it were, into each other, as in the former case; and the result is a permanently existing polarization throughout the whole series, constituting what has been termed *insulation* (8) (11), and by which a sort of propagation of force is obtained throughout a series of particles, until the force reaches some limiting conducting surface, and appears there at a distance from the point in which it originated. By the term *contiguous particles*, we are to understand, *following* particles, or *next* particles, without any relation to the question of nearness, or of indefinitely small distances between such particles (38); by *polarity* we understand, also, such a disposition of force as enables the same particle to acquire opposite powers in different parts, as represented in fig. 20 (38).

99. We see, then, according to these views, that the first effect of an electrically charged or excited body upon an insulating medium is upon the particles of the medium immediately next it: these operate in a similar way upon the following or contiguous particles, until the force extends to some distant body; and there is probably no distance so great as to be without the reach of this progressive propagation, although with the same originating force the polarization goes on more easily as the extent of the medium is lessened, since there will be in this case fewer particles in the line of action opposing a united resistance to the polarized state, which we must ever consider as a constrained state, being sustained purely by the force of the originating electrical charge. The annexed diagram, fig. 49, may serve to elucidate this more completely. Let A be a conductor, charged either positively or

negatively; B a distant neutral and similar conductor; and *a b c d e* intermediate particles of any insulating dielectric medium: then if A be charged positively, we obtain a series of

Fig. 49.



successive intermediate positive and negative forces symmetrically disposed, the negative after the positive, until we reach the *proximate* face of the conductor B; upon which, by the law of the series, a similar force will appear to that exerted by A, but of an opposite kind as to direction; that is, it will be negative; but as this progressive insulation of the particles or forces cannot exist in the conductor B, we only there obtain the polarized state as it were bodily, that is, where the insulating medium begins or continues, so that the next companion force is found towards its more distant parts; thus, whilst the intervening dielectric medium is polarized, particle after particle, the limiting conductor is polarized as a whole: but if we can in a distant conductor B obtain in this way a similar force in effect, although opposite in direction to that of the permanently charged body A, it may be inferred, as we have shown experimentally (21), that this newly developed force should also operate or re-act by a sort of return action upon the original conductor in a very similar way, by which the state of polarization would be further exalted; the return action would in fact conspire with the original power of polarization as to the position of the intermediate forces, much in the same way as would arise supposing the distant conductor B to be also permanently charged with a force opposite in direction to that of A; in which case it is evident that both conductors would act similarly. If we consider the successive polarities, fig. 49, to be lines of force (39), then since the force in any point of such a series is made up of the forces acting in all directions, that is, the resultant of such forces, we may conceive the existence of a relative force transverse or oblique to the lines

A B of the direct inductive forces, equivalent to a dilatation or repulsion of such lines, and which may be expressed by the term *tension*.

100. Such, then, we may conceive to be the existing state of things in every case of electrical action at a distance; so that attraction by electrical agency is really the consequence of charge, as in the Leyden experiment: we require for its development two oppositely electrified surfaces, usually limiting conductors, with an intermediate dielectric medium, the particles of which become polarized in a similar way in each direction. Repulsion, on the other hand, originates in a similar electrical arrangement; but in this case the intermediate polarization is not the same in both directions, but subversive.

LAWS OF ELECTRICAL ACTIONS AT A DISTANCE.

101. Induction being the immediate source of all electrical force, and the great preparatory process upon which both attraction and repulsion depend, we should, in any substantial investigation of the laws of electrical action, necessarily commence with the nature and mode of operation of these inductive changes. Now we have seen (20) (21) (99) that in the operation of a charged on a neutral conductor an impression is first made on the near surface of the neutral body, where it calls into action a force opposite in kind to that of the electrified body which originated the induction, this new force (22) (99) becomes reflected or reverberated as it were upon the opposite charged surface, impressing upon that surface what may be considered as a new force, similar in kind to that with which the body is supposed to be electrified; in other words, it determines a portion of the charge in the line A B, fig. 49, of the induction,—for it is important to recollect here, that we really know nothing of the actual condition of what we call an electrified body, except through the medium of certain other bodies which we present to it, or which in some way operate on it. What would be the actual state or distribution of the electricity in a charged conductor, supposing it placed in pure space,

apart from all disturbing influences, it is really difficult to say; we may certainly infer upon some well-grounded hypothesis or theory what it should be, but it is an hypothetical deduction after all. Now we have experimental evidence (22) to show that the result of the reverberative or secondary induction (99) is to determine a given portion of the electricity of the charged body to the surface next the neutral body (21), Exp. 15. This then is the nature of the reflected or return action.

We may further infer that a reverberative effect such as this being once set up, may continue beyond the first terms, giving rise to a second direct and return force, and so on, until the action sinks away in rest; much in the same way, to use a mechanical analogy, as a wave set up in a long narrow tray, partly full of water, will continue to flow between the terminating planes at its extremities, until it vanishes in the general level of the surface.

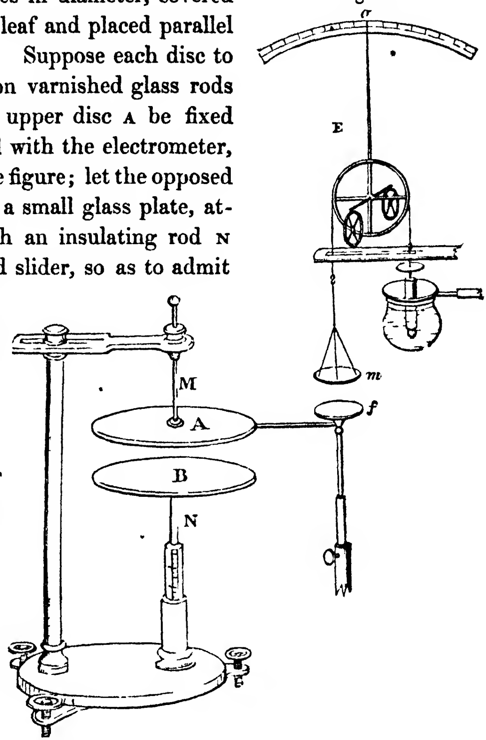
Murphy, in his valuable mathematical work on Heat and Electricity, adopts a view of electrical induction not very dissimilar to this, under the title of 'Principle of Successive Influences:' he employs it to obtain numerical approximations to the state of electrized bodies influencing each other, by calculating the effects of 4 or 5 successive acts of influence. Professor W. Thomson, also, of the Glasgow University, resorts to a similar principle, conceiving that in the reciprocal action between a charged and neutral conductor, reflections of force are produced within the opposed surfaces, which reflections are perpetuated *ad infinitum*, much in the way of optical reflections between two mirrors; then calculating the several effects of these reflections, he endeavours therefrom to arrive at the law of the force in action.

102. This understood, we will proceed to consider the laws and operation of these direct and reflected inductive forces, and which may be satisfactorily investigated by the following experimental process:

Let A B, fig. 50, represent two light circular plane discs,

about 10 inches in diameter, covered with metallic leaf and placed parallel to each other. Suppose each disc to be insulated on varnished glass rods M N; let the upper disc A be fixed and connected with the electrometer, as shown in the figure; let the opposed disc B rest on a small glass plate, attached through an insulating rod N to a graduated slider, so as to admit of being easily removed and replaced, and set at given distances from A, measured from the points of contact. In this arrangement we have, as is evident, all the conditions of the Leyden experiment, and full means of examining experimentally the laws regulating the inductive action of the discs on each other.

Fig. 50.



Exp. 38. Connect the upper disc A with the ground, and set the attracting plates *f m* of the electrometer to a given measured distance, say ·6 of an inch; separate the discs A B also by a given measured distance, say ·4 of an inch. This being done, charge the insulated disc B with a given measured quantity of electricity by touching it with the knob of a small transfer jar electrified to a given amount, or by any of the methods already described (94). The result will be that a similar quantity will leave the disc A and pass off into the

ground (64) (65) (42). Now the quantity of electricity which has been thus displaced from A may be considered as the direct induction of B on A. In order to measure this induction, remove the wire connecting A with the earth, and discharge and remove the plate B; the electrometer will then indicate in degrees the resulting force at the given distance, A B, viz. ·4 of an inch, in terms of the opposite electricity (53). If we repeat this experiment at 8 and 12 tenths of an inch, that is, at twice and three times the former distance, we shall obtain the electrical force at these distances in a similar way. Now in this case the forces in degrees, as expressed by the electrometer, are inversely as the second powers or squares of the distances between the plates A B. Hence the respective quantities of electricity displaced, are in the simple inverse ratio of these distances, being by the law of the electrometer (88) as the square roots of the forces. The following Table contains the results of a series of experiments as actually observed:

Distance in tenths . .	4	8	12	16
Force in degrees . .	36	9	4	2 +
Quantity of induction .	6	3	2	1·5

It appears then, by this Table, that the direct induced force is inversely as the distance, since the distances increasing as the numbers 1, 2, 3, 4, the quantity of induction decreases as the numbers 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$. It is requisite in this experiment to discharge and depress the plate B before removing it when the distance is small, so that no electricity may pass over.

If we make the distance between the plates constant and vary the quantity of electricity, the *induction*, measured in the same way, will be directly as the quantity; hence the induced force is as the exciting electricity directly, and as the distance inversely.

Exp. 39. We have in this last experiment taken the direct induction upon the disc A, whilst in a perfectly free or uninsulated state. Let therefore A now remain insulated, as shown

in the figure, and proceed to charge B with a given quantity of electricity, the distance A B being varied in successive experiments as before. In this case the direct induction will no longer vary in a simple inverse ratio of the distances, but will be in the inverse ratio of the square roots of the distances. Thus the distances between the discs A B being adjusted to 3, 6, 9, 12, the forces by a direct influence on A taken in degrees of the electrometer and in terms of the same electricity (20) were 16, 8, 5·5, 4, very nearly—being inversely as the distances; the relative inductions therefore, or quantities of electricity displaced (88), are, 4, 2·83, 2·35, 2, being the square roots of these forces. Whilst therefore the distances increase as the number 1, 2, 3, 4, the inductions decrease in the proportion of 1, ·7, ·6, ·5, nearly.

Exp. 40. Let the discs A B be separated by a given distance, suppose ·3 of an inch, and put the disc B in communication with the earth, in order to make its capacity for electrical change the greatest possible (42); communicate to the disc A a small measured charge, sufficient to move the index, say 2 degrees; under these circumstances place the disc B at other distances from disc A,—as for example, 6, 9, 12 divisions of the slide, or twice, three times, &c. the first distance—the forces indicated by the electrometer will be as the squares of those distances; that is to say, they will be 2°, 8°, 18°, 32°, respectively. Now as the quantity of electricity affecting the electrometer will be greater, as the return action taken as a neutralizing force is less (42), we may take this quantity as being inversely proportional to the reflected force; but the quantities of electricity affecting the electrometer will be (88) as the square roots of the above forces, that is to say, as the numbers 1·4, 2·8, 4·2, 5·6, which are as the numbers 1, 2, 3, 4. Taking the reflected force, therefore, as being inversely proportional to the square roots of the forces, we see that whilst the distances are 1, 2, 3, 4, &c., the reflected forces are 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$th.

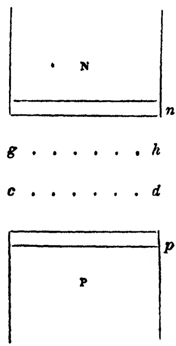
Exp. 41. If we take the opposed neutral disc B insulated as

before, Exp. 39, then the force as shown by the electrometer will be only as the simple ratio of the distances directly. The reflected force will therefore be in this case in the inverse ratio of the square roots of the distances, and will hence vary as in the former case, Exp. 39.

In these last experiments, the disc B being set to the given distance, a given measured quantity of electricity may be transferred for each experiment (94).

103. Such being the laws of these inductive forces, let us now see how they may be applied in explanation of the law of electrical attraction as exerted between electrified bodies placed at a distance from each other. In the annexed fig. 51, let P represent a charged and N a neutral conductor, reciprocally attracting each other at some distance, $p\,n$, taken as a unit of distance. In this figure let n be taken to represent the direct induction upon N, and p the return force upon the charged body P (101), and suppose that every particle in p attracts every particle in n, and reciprocally.

Fig. 51.



In this case let all the particles in $n = a$, and all the particles in $p = b$, then the total force at distance $p\,n = 1$ will be represented by $a \times b = a\,b$; for the attraction of one particle of n to all the particles of p will be as b, the attraction of two particles will be as $2\,b$, and so on, until we have attraction of all the particles $= a$, as $a\,b$.

Suppose now we diminish the distance $p\,n$, say to the line $c\,d = \frac{1}{2}\,p\,n$, then by experiments 38 and 40, induced force n becomes $= 2\,n$, and return force p becomes $= 2\,p$. In this case the total attractive force will be represented by $2\,a \times 2\,b = 4\,a\,b = 2^2\,a\,b$. For, taking the particles now as double particles, a will become $2\,a$, and b will become $2\,b$; then, reasoning as before, we have the attraction of one double particle of n for all the double particles in p, as $2\,b$ of two

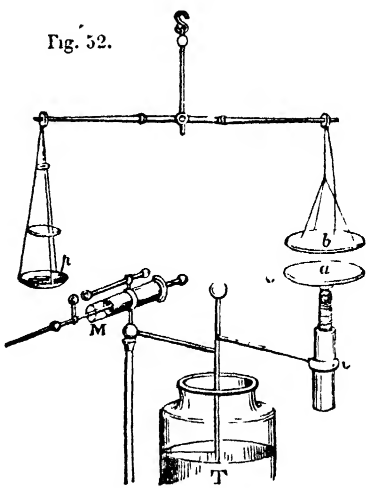
double particles in n for two double particles in p, as $2 \times 2\,b$ and so on up to all the double particles in p; which will be as $2\,a \times 2\,b = 2^2\,a\,b$. Suppose the distance $p\,n$ to be now diminished to the line $g\,h = \frac{1}{3}\,p\,n$, then, Exp. 38 and 40, force n becomes $3\,n$, and force p becomes $3\,p$; calling all the particles in $n = 3\,a$, and all the particles in $p = 3\,b$, we have total force $= 3\,a \times 3\,b = 9\,a\,b = 3^2\,a\,b$, and so on.

Thus whilst the distances become $1, \frac{1}{2}, \frac{1}{3}$, &c., the forces become $1, 2^2, 3^2$, &c., that is to say, they increase in the inverse ratio of the second powers or squares of the distances, and become 1, 4, 9, &c.,—so that at one-half the distance the force is 4 times as great, at one-third the distance 9 times as great, &c.

104. This deduction supposes that both the bodies P N are in a perfectly free state, and susceptible of the inductive changes upon which the forces depend. It may be verified experimentally in the following way.

Exp. 42. Let the lower disc a of the scale-beam electrometer already described, fig. 43 (89), be placed in communication with an electrical jar T, fig. 52, exposing about 3 feet square or more of coated glass: set the discs $a\,b$ at some given measured distance from each other by means of the graduated slide at c, suppose ·4 of an inch; let the suspended disc b be accurately balanced by weights placed on the scale-pan

Fig. 52.



at *p*, and connect it with the outer coating of the jar, through the metal of the instrument, by means of a fine wire hung from the arm of the beam and touching the upper surface of the disc; place a given weight in grains in the scale-pan *p*, say 18 grains, and charge the jar with measured quantities of electricity, through a unit measure M (93); find the number of measures required to turn the beam; take this number as a unit of quantity; let the jar and discs be now discharged; increase the distance between the discs to twice the former distance, viz. ·8 of an inch. Let 4·5 grains only be now placed in the pan *p*, continue to charge the jar as before; when the same number of measures taken as a unit of measure have passed into the jar, the beam will turn again. Thus the quantity being constant, the weights equivalent to the respective forces of attraction are as 4 : 1, being as the squares of the respective distances inversely, which are in this case as 1 : 2. If we repeat this process at 3 and 4 times the first distance, adjusting the weights in the scale-pan *p* to 2 grains, or the one-ninth and to 1·25 grains, or the one-sixteenth of the first weight, nearly the same result will be obtained; the beam with the same unit of quantity will turn at the given distances with the greatest precision. Thus the distances being as the numbers 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, the weights will be as the numbers 1, 4, 9, 16, taking in this case the greatest distance as a unit of distance.

The student will take care in this experiment not to load the scale-pan with a weight greater than equivalent to the striking distance of the plates, otherwise the jar will discharge across the interval (91). It is further desirable to turn the small stop, shown fig. 43, under the arm of the beam, so that it may not descend below a given point.

Exp. 43. Place the electrometer, fig. 42 (88), in connection with the system A B, as represented fig. 50 (102), Exp. 40; adjust the discs *m f* of the electrometer, E, fig. 50, to some given distance, as for example, 2 inches (88). The index being at zero of the arc, depress the water vessel until it

declines a small quantity, say 2 degrees; charge the discs A f with a measured quantity of electricity sufficient to bring the index to zero of the scale; we have then the force of this quantity at distance 2 inches: under these arrangements lower the suspended disc f an inch by means of the rack and pinion on the column of support. The index will then advance, probably 10 degrees or more. Let the water vessel be still further depressed, so as to bring back the index to zero, we have then the attractive force at a distance = 1 inch, whatever that force may be: to ascertain this, discharge the electricity of the system, and the declination of the index is the force in degrees required. Let the system be again charged so as to bring the index to zero, and again depress the suspended disc f until a less distance is obtained between the discs, suppose ·5 of an inch, or one-fourth the first distance; continue to depress the water vessel carefully, as the index now rapidly advances, until the index is again at zero of the arc; we have in this case the force at $\frac{1}{2}$ an inch, which we determine as before by discharging the electricity. If we now compare the distances with their respective forces, the forces will be found as the squares of the distances inversely. Thus the force at distance 2 inches being 2 degrees, the force at one inch will be 8 degrees; the force at ·67 will be 18 degrees; the force at ·5 will be 32 degrees, or at least so nearly so as to leave no doubt as to the law which we are seeking. If therefore we take the first distance of 2 inches as unity, then whilst the distances are 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, the forces are 1, 4, 9, 16.

A similar result may be arrived at by observing the advance of the index, without adjustment, to the zero of the arc, but then we must calculate the new distance, if we require a very perfect experiment, in the way already explained (88).

There is little or no difficulty in this experiment; all we require is great perfection in the insulations (29), an accurate and sufficiently delicate instrument, and careful manipulation.

105. It is evident in these experiments that the attracting

discs may be considered as being both in a perfectly free state, the suspended disc through its connecting wire and the metal of the instrument by which it communicates with the earth; the fixed disc by its forming part of the large surfaces of induction, which the coated systems in connection with it supply. In this case, therefore, we may conceive the two discs as tending toward each other, by the general laws of inductive force which we have just enumerated (102). Let us however now take the case in which we may conceive the induced forces to be limited or restrained, as shown in Exp. 39 and Exp. 41 (102). Then referring to fig. 51, and adopting the same notation and reasoning as before (103), when we diminish distance $p\,n$ to one-half, n instead of becoming $2\,n$ is only $1{\cdot}4\,n$, and p instead of becoming $2\,p$ is only $1{\cdot}4\,p$, since the forces are as the square roots of the attraction, as taken in degrees of the electrometer. We have therefore in this case the reciprocal force at distance $\frac{1}{2}$ represented by $1{\cdot}4\,a \times 1{\cdot}4\,b = 2\,a\,b$. In like manner, at distance $\frac{1}{3}\,p\,n$, we have the reciprocal force represented by $1{\cdot}73\,a \times 1{\cdot}73\,b = 3\,a\,b$, the induced forces being still as the square roots of the distances, so that in such a case, whilst the distances are 1, $\frac{1}{2}$, $\frac{1}{3}$, &c., the forces are 1, 2, 3, &c., that is to say, they are as the square roots of the distances inversely.

This result may be verified experimentally by removing the large surfaces of induction A B, fig. 50, with which the lower disc of the electrometer communicates, and taking the forces between the discs of the electrometer only: one or both the discs may in this way have their capacity for electrical charge limited, as exemplified in the following experiments.

Exp. 44. Take the discs A B of the electrometer, fig. 42 (88), both insulated, charge one A positively, the other B negatively, which may be easily effected in the way before explained (94); the forces taken at different distances, as in Exp. 43, will be in the inverse ratio of the distances.

Exp. 45. Take the suspended disc B uninsulated (88), and

charge the fixed disc A either positively or negatively; examine the forces at different distances as in the preceding experiment, and the same law will be apparent.

The operator must be careful at the near distances to depress the water vessel before communicating the charge, or bringing the discs toward each other, otherwise by a sudden impulse the balance will be overset.

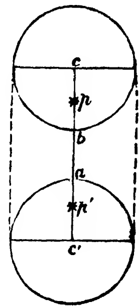
In all these cases of electrical attraction it is quite immaterial to the conditions of the experiment whether one or both the bodies be permanently charged. In the case of both bodies being permanently charged, and with opposite electricities, then, as already observed (99), both bodies act similarly. In order for the force, however, to vary in the inverse duplicate ratio of the distances, they must always be so circumstanced as to have a large inductive capacity.

106. Although the laws of electrical force which we have thus arrived at are such as commonly appear to obtain in the operation of attractive force in electricity, yet other laws of force are still possible, and by no means improbable, under other laws of augmentation in the reverberatory or inductive actions (101). Suppose, for example, that these successive influences should be such under any possible electrical conditions, that induced force n, fig. 51, instead of becoming $2\,n$ when the distance $p\,n$ was diminished to $\frac{1}{2}$, should become $2{\cdot}8\,n$, and p instead of becoming $2\,p$ should become $2{\cdot}8\,p$; then taking all the particles in $n = a$, and all the particles in $p = b$, as before, we have the force at distance $\frac{1}{2}$ represented by $2{\cdot}8\,a \times 2{\cdot}8\,b = 8\,a\,b = 2^3\,a\,b$, that is to say, when the distances are as $2 : 1$, the forces are as $8{\cdot}1$, being as the 3rd power, or cubes of the distances inversely. In this way we might obtain laws of force as the 4th or any other power of the distance inversely, did such laws exist.

107. We have in these preceding experiments considered the attractive force as operative between limiting plane surfaces, and in opposed points of which the forces of attraction are all equal; we may, however, from the laws which we have

deduced, obtain the law of force as regards bodies of various other forms. We will take for example the reciprocal attractive force between a charged and neutral sphere, a question which has engaged the attention of many profound mathematicians, as being a physical problem of deep interest. We may in this question, upon the principles before laid down (100), consider the opposed hemispheres *a b*, fig. 53, as being the terminating curved surfaces, or coatings, to the medium intervening between them; for as we may readily infer from the nature of inductive actions, and from the general principles of coated electrics, the distant or unopposed hemispheres have no share whatever in the attractive force.

Fig. 53.



Now the attractive force between the opposite hemispheres *a b* may be taken as the number of attracting points; that is, as the areas directly, and as the squares of the distances inversely. Upon this basis, we may by a simple mathematical analysis determine two points $p\,p'$, fig. 53, within the surfaces of the opposed hemispheres, in which we may conceive the whole force to be collected, and to be the same as if proceeding from every portion of the hemisphere. The total force therefore should be in the inverse duplicate ratio of the distances between these points, determinable by similar experiments to the preceding, as in Experiment 42. The formula is $z = \frac{(a^2 + 2\,a\,r)^{\frac{1}{2}} - a}{2}$, in which a = distance $a\,b$, that is, the distance of points $a\,b$ in which the two spheres would touch r = the radius of spheres, and z = distance of points of concentration $p\,p$ within the hemispheres. When both hemispheres are equal and the distances variable, then we find from the same analysis that the attractive force will be as $\frac{1}{a\,(a + 2\,r)}$, that is, in the inverse ratio of the distance between the near points $a\,b$ of the hemispheres $= a$, multiplied into distance between

the centres $= a + 2r = c\,c'$.* From the above formula it appears that the precise position of the points $p\,p'$ will depend on the distance a, that is, on the distance of the near points of the spheres, and that the further the spheres are removed from each other, the more nearly the points $p\,p'$ approach the centre.

We may verify the truth of this formula by experiment, by means of the arrangement exemplified fig. 52 (104), substituting for the plane discs $a\,b$ two spheres of 2 inches in diameter, in which we have $r = 1$ inch: these spheres may be of wood neatly gilt; the suspended sphere should be hollow and light, and may weigh about 200 grains.

Exp. 46. The experiment being thus arranged, the following results were obtained. When distance $a\,b$ was ·5, and distance of points $p\,p' = 1{\cdot}11$, a weight of 6 grains was required to balance the attractive force, a given measured quantity of electricity being communicated to the system.

When distance $a\,b$ was increased to 1 inch, or twice the former distance, and distance $p\,p'$ became 1·73, then with the same measured quantity of electricity, about 2·5 grains of resistance only were required. On increasing distance $a\,b$ to 2 inches, distance $p\,p'$ became 2·83, about ·9 of a grain, or something less than a grain balanced the force. The distances and forces will therefore be as follows:

Distance of points $p\,p'$	1·11	1·73	2·83
Distance $a\,b$ × distance $c\,c'$	1·25	3	8
Forces in grains	6	2·5	·9

It will be seen here that the forces are inversely proportional to the squares of the distances $p\,p'$ and in a simple inverse ratio of the distance $a\,b$ × into distance $c\,c'$, as given in the two upper lines of the Table. To avoid a long detail, three terms only have been quoted of this experiment.

* See Transactions of the Royal Society for 1834, p. 240.

Exp. 47. The general result thus apparent may be more fully confirmed by substituting for the spheres two light circular discs, each exactly equal in area to the superficies of the hemispheres *a b*, or very nearly so, and placing these at distances *p p'*, so as to bring as it were every point of attraction into one plane. If this be done, and the arrangement completed as before, Exp. 42 (104), we shall obtain the same force between the planes as between the spheres.

108. In turning our attention to repulsive forces in electricity, we may observe that similar inductions equally tend to arise in the case of two repellent surfaces, as in that of two attractive surfaces, Exp. 17 (23). These inductions, however, are subversive of the already existing electrical states, which is probably the source of the repulsive action. Repulsive force, therefore, by the agency of electricity, admits of the same kind of analysis as that which we have applied to attractive force (103), except that we take the inductive forces in the sense of being resisted by the already existing electrical states, and consider the bodies as being both permanently charged.

In submitting repulsive forces to experiment by any of the preceding arrangements (104), the opposed discs must evidently be both insulated, and the suspended disc *b*, fig. 52 (104), charged with the same electricity as that to be collected on the fixed disc *a*. In such a case as this the arm of the balance carrying the suspended disc must be allowed to rest on a small stop, fig. 43 (89), and the resisting weights placed on it, or otherwise a given measured resistance obtained by removing small weights from the opposite scale-pan. In the application of the electrometer, fig. 42 (88), to forces of repulsion, we charge the discs with the same electricity, by means of the quantity jar (94), and determine the forces as in Exp. 43 (104), by an adjustment of the index to zero of the arc.

Electrical repulsion being dependent on limited inductive capacity and influenced by inductive changes subversive of the

already existing electrical states, will be always open to great irregularity and disturbance, so much so that when the forces are unequal one of the electricities gives way, and in all cases the electricities yield more or less to each other's inductive influence (23); hence it is by no means an unfrequent occurrence to find two electrified bodies repel at one point of distance and attract at another. Supposing, however, the resistance equal to the inductions and the opposite electricities permanent, then, in cases such as those to which we have just referred, the force will be in the inverse simple ratio of the distance between the opposed planes.

109. Cavendish endeavours to show, in his fine Mathematical Dissertation on Electrical Action, (inserted in the 61st volume of the Transactions of the Royal Society,) Prop. v., that on the supposition of electricity being an elastic fluid, the mutual repulsion of the particles should be in the inverse duplicate ratio of the distances; from which it must follow, that in the case of a sphere being charged with electricity, all the fluid should be found on its surface, and the action upon any interior point be reduced to zero. It was with a view of verifying this deduction, that he contrived the beautiful and conclusive experiment to which we have before adverted, fig. 12 (24), and he found the result accord with the theory. If the force had been in any higher inverse ratio than that of the square, then he shows that the inner globe would be in some degree overcharged,—if less, it would be undercharged; now, by his electroscope it was neither; by which he at least proves that the repulsion must be inversely as some power of the distance between that of the $2 + \frac{1}{50}$ and that of the $2 - \frac{1}{50}$th; so that "there is no reason to think that it differs at all from the inverse duplicate ratio." Mr. Cavendish's theorems are all given in a general and abstract mathematical form, applicable to any law of force whatever; and are hence easily accommodated and applied to the French theory of two fluids.

110. In the year 1780, soon after Cavendish's 'Memoirs'

had appeared, the celebrated Coulomb applied the powers of his inventive genius to the investigation of electrical force, and found by the aid of his torsion balance (86) that two small spheres similarly charged repelled each other with a force inversely proportional to the squares of the distances between their centres. Thus the re-active force of torsion (86) at distances 36° and 18° were 36 and 144; so that with a decrease of distance to one-half, the force had increased in the proportion of 1 : 4. The electrical inquiries of Coulomb have deservedly engaged the attention, as they have challenged the admiration, of scientific men: Biot, Poisson, and other of the French mathematicians rest their mathematical theory of electricity entirely upon the researches of this distinguished philosopher.

In prosecuting this subject experimentally, Coulomb directs his attention to the distribution of electricity upon the surfaces of bodies, where it is supposed to be confined in a stratum of greater or less density by atmospheric pressure, and to exist as it were within a hollow vase of air of the form of the body. He endeavours to deduce experimentally the general laws of this hypothetical distribution, by touching electrified bodies with a small insulated carrier plate, termed the 'proof plane,' and which he subsequently transfers to the balance of torsion (86). This plane, on removal from the electrified body, is considered as an element of the surface, and to be in all respects identical with it: in this way he deduces the law of electrical distribution for spheres, plates, cylinders, and bodies of various forms, and the proportion in which a charge is shared between such bodies, together with the thickness of the supposed electrical stratum at different points. This stratum in cylinders and plates is greatest and most dense towards the extremities or edges: at the point of contact of two unequal spheres it is nothing. In the extreme opposite points the ratio of the density increases in proportion to the diminished size of the lesser sphere, but it never surpasses a given limit. When the spheres are separated, the limit of ratio of the densities of the stratum in each is $\frac{5}{3}$.

111. Although the mathematical and experimental researches of the French philosophers in this branch of physics are unquestionably amongst the highest efforts of genius, yet the theory is by no means so perfect and so fully confirmed by further advances in electricity as to place it beyond the region of conjecture.

What may possibly be that peculiar state of a given substance which we term electrified, taken in space apart from all surrounding influences, it is, as already observed, extremely difficult to say, although it is not perhaps so difficult to assign what it would be upon the assumption that electricity is a subtle elastic fluid, capable of assuming different states of density, and the particles of which repel each other, according to a certain law; still, if electrical phenomena be supposed to depend on a repulsive force immediately impressed upon the molecules of common matter, then, as must be admitted, it is a species of force essentially different from any repulsive agency in nature of which we have the least experience. Its operation extends through great distances, and is by the hypothesis exerted between distinct and concentrated accumulations of the repulsive agency disposed on the surfaces of bodies; and whilst thus exerted at very sensible distances, the assumed force between the molecules themselves, at insensible distances, is so feeble as to be incapable of expansion when all electrical resistance to such expansion by the pressure of the atmosphere is removed (34). It is besides very doubtful whether any indefinitely thin carrier plate, such as the proof plane, can be altogether considered as an element of the surface of an electrified body to which it is applied,—whether it fairly represents the actual amount of electricity accumulated in that point; and if it did, whether the laws of repulsive forces are so uniform and invariable with all charges, and at all distances, as to enable us to deduce therefrom the ratio of the intensities. It is well known that proof planes of variable thickness come away charged from the same point of electrified bodies in different proportions,—the power to take up

electricity being entirely determined by the induction of which it is susceptible: it can be further shown, that notwithstanding the presence of similar or dissimilar electricities, inductive forces tend to arise in two opposed conductors, similar to those which would arise supposing one of the bodies in a neutral state,—thereby, with certain charges and at certain distances, decreasing the amount of the repulsive force, and disturbing the law of action: all question of the accuracy of deductions, therefore, upon the evidence of the proof plane, is not altogether unpardonable; nevertheless, the beautiful memoirs of the French philosophers, and of Coulomb especially, upon this branch of physics, will be always regarded as among the most splendid efforts of genius and intelligence.

LAWS OF ELECTRICAL CHARGE.

112. The quantity of electricity which may be disposed upon insulated conductors of various kinds, form, and dimensions, under the same degree of divergence of an electrometer (85), was conveniently enough expressed by Cavendish by the term *charge*. Imagine, for example, a sphere, a cylinder and a circular plate to be charged with electricity, and that an electrometer (85) being applied to each in succession, stood at the same angle of divergence; then the actual quantity of electricity in each of these bodies is termed their *charge*, and is very different in the three bodies, even although the superficial area may be the same, or nearly so.

In treating this question, we have to determine first the effect of different quantities of electricity disposed on the same surface, and the effect of the same quantity on surfaces of greater or less extent.

When different measured quantities of electricity are disposed on the same surface, the forces, as indicated by an electrometer, will be as the square of the respective quantities.

Exp. 48. Connect the plate B, fig. 50 (102), with the ground, and separate the two plates A B by a given distance, suppose ·4 of an inch; connect the upper plate A with the

electrometer; set the attracting discs *m f* also at a given measured distance from each other, suppose ·5 of an inch; charge the insulated plate A in successive experiments with different quantities of electricity (94), the march of the electrometer will be as the squares of these quantities; that is to say, with twice the quantity of electricity the force will be four times as great; with three times the quantity, nine times as great, and so on, which is the law already alluded to (88) as affecting the instrument. The same result may be obtained by means of a simple insulated plane or other conductor, K, fig. 42 (88), placed in connection with the lower disc A of the instrument.

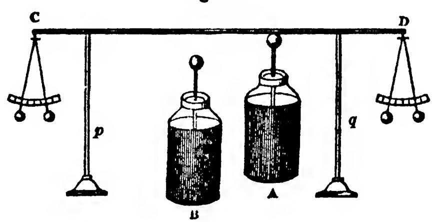
Exp. 49. Let this experiment be repeated with the scale-beam electrometer, fig. 43 (89), according to the arrangement before described (104). The plates being set at a given distance, the beam will turn with weights which are to each other directly as the square of the number of measures thrown on the jar.

This law of quantity is apparent in the operation of the induced forces we have just considered (103), in which it will be seen that the force is always as the square of the induction. Thus, Exp. 42 (104), when the induced force is as the numbers 1, 2, 3, &c., the total or reciprocal force is 1, 2^2, 3^2, &c.; so that the law of the attraction may be as well said to vary as the square of the induction directly, as with the squares of the distances inversely. If we adopt, therefore, the same form of notation and reasoning as before (103), we shall arrive at precisely the same result, since instead of varying the distance, we vary the quantity of electricity.

113. The Hon. Mr. Cavendish, as appears by his most valuable and interesting manuscripts, had anticipated this result so long since as the year 1772, and verified it in the following ingenious way, which, considering the state of experimental electricity at the time he wrote, is very characteristic of his great powers of philosophical research.

"If two bodies," he says, "A and B, placed near each other, be connected to the same Leyden jar, and the quantity with which the jar is electrified is varied, then the force with which A and B repel each other ought by the theory (36) to be as the square of the quantity of redundant electricity in the jar, supposing the distance of the bodies to remain unaltered. In order to try this, I made use of the following apparatus: A metallic rod C D, fig. 54, about 43 inches long, is supported on insulators p q; at the extremities C D are suspended two electrometers (85); A and B are two electrical jars, which, for the sake of brevity, we will consider as being precisely equal and similar in all respects: these jars are placed on a conducting base communicating with the ground; one of them, A, touching the metallic rod C D. I first compared electrometer C with electrometer D, without either being loaded with weights (85), and found that when the jar A was electrified to such a degree as to make D separate 12·5 divisions of its scale, electrometer C separated 13·7 divisions. I then put weights into electrometer D, and again electrified the jar A until D again separated 12·5 divisions." A communication was now made between the charging rods of the two jars, so as to divide the electricity between the two jars (69); electrometer C now separated 13·7 divisions as before. Now "it appears by the first part of the experiment, that the same degree of electrification which made C separate 13·7 divisions, makes D without the wires separate 12·5 divisions; so that when the electricity is shared with the uncharged jar B, the remainder in jar A will be of that degree of strength requisite to make the same electrometer D, without the wires, separate 12·5 divisions, as at first,

Fig. 54.



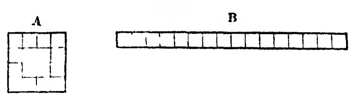
before the electricity was divided. But if the jars be equal, the quantity of electricity in the rod C D, and electrometers, and in the jar in communication with them, will be only one-half what it was before; and as the quantity spread over the rod and electrometers is comparatively small, we may consider the original quantity as being equally divided between the jars. It appears, therefore, that the distance to which the electrometer D separates, when loaded with the wires, and acted on by a given quantity of redundant fluid in the phial, is very nearly if not exactly the same as that to which it separates, without being loaded with the wires, with only half the quantity of electricity in the phial." Now the weights placed in the electrometer (85) were such as to increase the force, tending to close the reeds when diverging at a given angle, in the proportion of 3·9 : 1; that is, as 4 : 1, very nearly; hence "the force with which the balls of the electrometer are repelled with a given quantity of redundant fluid in the phial, is to that with which they are repelled when there is only half that quantity in the phial, as 4 : 1, that is to say, as the squares of the quantity of redundant electricity, or very nearly; hence the experiment agrees very well with the theory."

114. *Law of charge as regards surface.*—When the same quantity of electricity is disposed on surfaces of variable extent, the force will be in the inverse duplicate ratio of the surface; that is to say, the same quantity of electricity disposed on twice the surface only evinces one-fourth the attractive force: this is evidently a necessary result of the preceding law; it is, in fact, virtually the same law: for imagine that in Exp. 48 (112) the charge were disposed on twice the extent of surface, then there would be only half the quantity of electricity in any one point, and the discs A B may be considered as being charged with only one-half the electricity: but in this case the electrometer force would be reduced to one-fourth, since, by the preceding experiments, it is as the square of the quantity.

This law admits of verification by experiments similar to the preceding, the only difference being that we vary the surface and keep the quantity constant.

115. We may here take occasion to notice one or two interesting features in this law of electrical charge, as regards simple insulated conductors, of no small importance. Volta has long since observed, that extension in length increases the capacity of a conductor for electricity; or, in other words, that the charge, say of a plate 1 foot square, will be much less than the charge of a plate 2 feet long by 6 inches wide, although each contain the same amount of surface. The author has further shown in the Transactions of the Royal Society for 1834, that the charge of insulated plates will also depend on the perimeters as well as the surface; so that to obtain a double charge, the electrometer being the same, we must not only double the surface, but place the surface under such a rectangular form as shall also give twice the perimeter. To obtain a treble charge, we must have a treble surface and three times the perimeter, and so on, which is the law for the transfer plates before alluded to (94). Now although it may be inferred from this that the increased capacity would result from an increase of linear boundary, yet such is not the case; the same plates turned into cylinders or hollow bodies of other forms evince the same capacity. Thus the charge of a sphere does not differ from that of a plane circular area of equal surface. This law of electrical charge, therefore, is likely to depend, as suggested by Volta, on the particular grouping of the electrical forces or particles in the several cases. Thus if, as in the annexed fig. 55, we take a plate A, 4 inches square, and divide it by cross lines into sixteen square parts, the grouping will be very different from that of a plate B, 16 inches long and 1 inch wide, divided also into sixteen square parts. The least charge, therefore, of a given surface

Fig. 55.



will be under the form of a circular plate, the greatest under that of a rectangle of very small breadth.

These laws, so far as the inquiries extend, apply only to simple insulated conductors: in the case of coated surfaces in which the charge is mainly dependent on the induction of an approximative conductor, a similar result may not be obtained. The experimental investigation with simple insulated conductors may be readily pursued by means of the quantity jar (94) and the hydrostatic electrometer (88).

116. Cavendish, as appears from his manuscripts, examined the law of charge for various bodies of different kinds and forms by a method peculiarly his own. In effecting this he employed an insulated plane, the surface of which could be extended or contracted by a given measurable amount. He says, "the method I took in making these experiments was by comparing each of the two bodies I wanted to examine, or A and B, as I may call them, with a third body, and which I shall call the *trial plate*. In this manner I took two Leyden phials and charged both of them from the same conductor. I then electrified B positively by the inside of one of the phials, and at the same time I electrified the trial plate negatively by the coating of the other phial. Having done this, I tried whether the redundant fluid in B was more or less than sufficient to saturate the redundant matter in the trial plate, by making a communication between them. If the redundant fluid in B was more than sufficient, both should be overcharged after the communication: on the other hand, if not sufficient, they would be undercharged. In this way I found what size the trial plate must be to saturate the redundant fluid in B. I now tried the body I call A in the same way, and if I found that it required the trial plate to be of the same size, in order that the redundant matter in it should be just sufficient to saturate the redundant fluid in A, I was well assured that each would contain the same quantity, and that the charge of A would equal the charge of B."

The limits of this work do not admit of any particular

detail of the ingenious experiments of this profound philosopher and mathematician; the following, however, are a few of the most striking results at which he arrived:

1. The particular position of a body has no influence on its charge, which is the same in all positions.

2. The charge is independent of the nature of the substance, provided it be similar as to form and expose the same surface; thus the charge of a square foot of freestone is the same as that of a square foot of wood or metal.

This fact was also made evident by the French philosophers: Coulomb found that an equal division of electricity took place between insulated conductors of equal surface and similar form, without regard to the kind of substance of which they consisted.

3. The charge of a thick plate is greater than that of a thin plate, and is equal to that of a very thin plate whose side exceeds that of the thick plate by about $1 + \frac{1}{8}$ its thickness.

4. The charge of a circular plate is to that of a globe of the same diameter as $12 : 18\frac{1}{2}$.

5. The charge of a square plate is to that of a circle whose diameter equals the side of the square as $1{\cdot}53 : 1$.

6. If two hollow globes be placed concentrically one within the other, but not touching, and the outer globe communicate with the earth, then if we charge the inner globe by a conducting rod passing through the outer but quite insulated from it, "the quantity of deficient fluid in the outer globe will be equal to the quantity of redundant fluid in the inner globe, and the quantity in the inner globe will be to that which it would contain if the outer globe were away as semi-diameter of the outer globe is to the distance between the two globes."

7. If in the middle of a spherical room, 16 feet in diameter, we suspend a globe 1 foot in diameter, the charge of this globe should be increased in the ratio of $16 : 15$, by reason of the undercharged surrounding surface.

It is not a little remarkable, that in the course of these inquiries Cavendish notices the difference in the charge of different electrical bodies coated with metals, especially the different kinds of glass; thus coming as near Faraday's modern discovery of specific electrical inductive capacity (22) as may be. "There is," says he, "a sensible difference in the charge of plates of the same dimensions, according to the different sorts of glass they consist of." And again, "The charge of a lac plate is much less in proportion to its computed charge than that of any glass plate; a plate of bees'-wax, or of the mixture of bees'-wax and resin, still less: as the difference seems to be greater than could well proceed from the electricity not being spread uniformly, I am inclined to think that it *must be partly owing to some difference in the nature of the plates*." (22.)

117. These inquiries are calculated to elucidate many phenomena of electrical action of much practical value. Thus in the operation of Lane's Discharging Electrometer, fig. 44 (91), we find that the quantity of electricity accumulated will be directly as the distance of discharge between the balls; that is to say, between the two most prominent points from whence the discharge proceeds; a law which admits of the following demonstration. Call the attractive force between the discharging points at the instant of discharge over a given distance unity or 1, and suppose the balls of the discharger to be now separated by twice the previous distance, then with the same previous accumulation the discharge could not now occur; the force of attraction between the discharging points being now only one-fourth the previous force (104), because it decreases as the square of the distance increases. Suppose now that we accumulate twice the quantity of electricity in the jar, then the force of attraction will become four times as great (112), since it is directly as the square of the quantity; that is to say, it will be four times one-fourth, or unity, as at first. In this case, the discharge will occur again, since the resistance of the air is constant for all distances, and we have

only to obtain a force of attraction in the discharging points somewhat greater than the resistance to be overcome, let the distance be what it may. Since, therefore, double, treble, &c. quantities of electricity develop attractive forces which are as the squares of these quantities, we exactly compensate the loss of force arising from a reciprocal increase of distance.

This law may be verified experimentally by charging a large jar *s*, fig. 44 (91), through the small unit measure, fig. 46 (93), the large jar being fitted with Lane's Electrometer, as shown in the figure. Then if we set the balls of the discharger to given measured distances, the number of unit measures requisite to produce discharge will, if the experiment be carefully performed, be exactly as those measured distances, or very nearly. Thus if ten measures produce discharge at a distance of two-tenths of an inch, twenty measures produce discharge at four-tenths, and so on.

118. The arrangement represented in fig. 50 (102) is directly applicable to a perfect analysis of the law of electrical accumulation in the Leyden jar, involving essentially the conditions of induction.

1°. Imagine for an instant that whilst the insulated plate A is charged with a given quantity of electricity, and at a given distance from the free plate B, the electrometer E indicates a certain number of degrees, say 16 degrees, it were possible to increase the area of these plates A and B, say to twice the amount; then the same charge being disposed over *twice the surface*, the electrometer would only indicate 4 degrees (114). Imagine then with this increased or double extent of coating, and the electrometer at 4°, we now proceed to double the quantity of electricity; we should, Exp. 48 (112), bring up the electrometer to 16°, as before. Hence the charge which can accumulate under the *same* degree of attraction or *electrometer* indication, is as the opposed areas directly; so that if the area and quantity of electricity vary together, the electrometer will remain unchanged; and hence, as is found to be the case, a given number of degrees of an electrometer may

with electrical jars of different magnitudes represent any accumulation whatever.

2°. Imagine that with a given distance between the plates A B, and a given quantity of electricity, and whilst the force evinced by the electrometer is a given number of degrees, say 4 degrees, we had increased the distance of the plates; suppose we had doubled it, then the attractive force between these plates would become reduced to one-fourth (104). Imagine now that the quantity of electricity is doubled also; then the force between the plates A B would be the same as before, since it varies with the square of the quantity (112). Hence the accumulation between two coatings is, under the same attractive force exerted between them, directly as their distances apart. Now all this time the indications of the electrometer E connected with the charged plate A are directly as the square of the accumulated quantity and the square of the distances between the plates, Exp. 49 (112), and Exp. 40 (102). If then with the quantity unity or 1, we suppose the distance between the plates to become twice as great, the electrometer action will be 4 times as great; that is, if it before indicated 4 degrees, it will now indicate 16 degrees (102): suppose at this instant we could take away one-half the electricity, the electrometer would then evince the same action as at first, that is, 4 degrees (112).

Hence it follows, 1°, that the charge which accumulates under a given number of degrees of the electrometer connected with the charged side, is as the surface directly, and 2°, as the distance between the opposed plates inversely, that is, inversely as the thickness of the intermediate electric substance, all other things being the same.

119. These results are in complete accordance with the deductions arrived at by Cavendish by a very different and totally distinct method of inquiry, so long since as the year 1775. He states, in the 66th volume of the Philosophical Transactions, that "the quantity of electricity which coated glass can receive under the *same degree* of *electrification* is as the area of the

coating directly, and as the thickness of the glass inversely." But the conditions of the two plates A B, fig. 50 (102), are precisely those of the Leyden jar, the only difference being in the dielectric medium, which in this case is *air* instead of *glass;* and although Faraday has shown that in respect of all such media there are differences of inductive capacity (22), yet for the same medium the specific inductive capacity is constant, and consequently the laws of electrical accumulation and attraction, as determinable in that medium, would not be far different from the laws in any other medium.

120. *Tension and Intensity.*—It may be proper, before closing our remarks, to advert to two terms frequently employed in Electricity, and which have given rise to some considerable discussion as to the sense in which they are to be received: these are the terms *tension* and *intensity*. Now with respect to the signification of such terms, inasmuch as they are abstractedly considered as mere signs of ideas, they may be taken to represent any previous definition we may think proper to assign to them. Their particular and direct application, however, to the representation of electrical actions, is tolerably clear and determinate.

The term *tension*, in its general acceptation, applies to the case of re-active or resisting force, however derived, whether to the re-active force of an elastic fluid, such as air heaving out under compression, or to the re-active force of a strained or twisted wire, as in the instance of a stretched musical string, or a wire employed in a balance of torsion (86). In either instance there is a force set up in these bodies by which they tend to recover their normal state; and the amount of this force is virtually the tension or degree of suffering to which they are exposed. If we conceive, therefore, for an instant, according to the French theory, that electricity is a certain force exerted by an elastic fluid, capable of compression, then, like any other elastic fluid, such as steam or air, it would exhibit a certain amount of tension or re-active power; and

this would be as the density or the number of particles confined in a given space: such would be the signification of the term electrical tension taken in this sense.

But the term may be also and equally well applied to the condition of polarized molecules of a dielectric interposed between two limiting conductors, as represented in fig. 49 (99), and to the state of induction generally. In this case it expresses the re-active force of the particles constrained to assume a new condition in their electrical relations, and the amount of suffering they endure in their forced deviation from their normal state. The higher the companion and separated powers are exalted, the greater will be the degree of tension which they endure. In a similar way, the lateral or transverse force of dilatation upon the representative line of induction is a kind of lateral tension or stretching of these forces, tending to throw the particles asunder, all of which may be conceived to increase up to the limit of the power of endurance: all this is fairly expressed by the general term *tension*, and which term thus becomes representative, either of the particular condition of the electrical agency itself, or of the re-active state of the molecules of a dielectric when charged by induction.

Now the term *intensity*, although of the same class, is still of a somewhat different character from *tension;* it rather applies to *degree* or *amount of resistance:* it would be no superfluity of language to speak, for example, of the *intensity* of the tension, as indicative of its greater or less amount in degree; just as we say, the *intensity* of the heat of the sun, the intensity of light, &c. In its application, however, to ordinary electrical phenomena, it has a proper and marked position assigned to it, being peculiarly expressive of the activity shown by an electroscope or electrometer as indicating the attractive force of a charge upon external bodies. Thus the charge communicated to a jar or battery may be taken in terms of the quadrant electrometer, or any other indicator, in which sense we speak of the jar being charged to a given *intensity;* but what renders this term as particularly neces-

sary and distinctive, is the fact that this activity or intensity is as the *square* of the *quantity* of electricity accumulated (112); whereas the *tension* or force on the dielectric particles actually constituting the charge itself between the limiting conducting surface, is as the quantity only, as is also the *tension* of the electrical agency itself when restrained to a given space. In the case of charged glass or other dielectric, the electrometer indicates the activity of the uncompensated electricity, or the free action, as it were, of the charged surface. This is one thing; but the *tension* or degree of power in the molecules of the intervening dielectric, tending to break down the induction by a species of mechanical violence, as in the case of a fracture of a charged jar, is another; and hence the two terms, tension and intensity, are under these limitations fairly and distinctly separable.

V.

ON ELECTRICAL DISCHARGE.

Various Forms of Discharge—Laws of Disruptive Discharge—Length of Electrical Spark—Influence of Pointed Bodies—Brush and Glow Discharge—Theoretical Views of Disruptive Discharge, and the Action of Points—Convective Discharge—Discharge by Conduction—Theory of the Action of Conducting Bodies.

121. The return of a charged system of electrics and conductors (61) to its normal or quiescent state constitutes electrical discharge, and is a phenomenon directly opposed to insulation: this return may be effected in various ways, giving rise to very different effects, and constituting different kinds of discharge.

The most palpable and violent form of electrical discharge is that which has been termed *disruptive discharge*, in which the particles of the intervening dielectric become more or less displaced, and the electrical polarization of the molecules, fig. 49 (99), is raised to a degree past endurance; so that the forces re-combine with a sort of convulsive effort, causing a sudden extrication of light and heat, and an almost irresistible expansive power. The common electrical spark, as drawn from the conductor of the electrical machine, and the dense concentrated explosion of the Leyden jar, between the balls of Lane's electrometer, furnish good illustrations of this form of discharge. Now, it is of little consequence to the immediate result, whether this take place either *directly* between the limiting conductors of the system, as in the case of the breaking down the intermediate dielectric medium itself, or whether it occur in some other direction between these limiting conductors, as in the case of an *exterior* circuit, such as is produced in applying a discharging rod to the discharge of the electric jar. In either case the polarized conditions of

the intervening glass vanishes, in consequence of the neutralization of the forces sustaining the induction. In the case of the exterior circuit, the return of the intermediate dielectric molecules to their normal condition is generally effected without any violence; but even here we find an occasional participation in the mechanical effect by which the jar, at the instant of the discharge is, as it were, forcibly penetrated in some point between the coatings, and a fracture is the consequence.

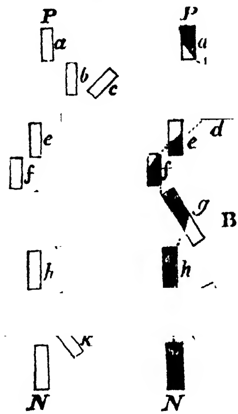
122. The laws of disruptive discharge are marked and decisive. If the insulation immediately between the limiting conductors sustaining the induction be sufficiently powerful, and the electrical forces allowed to determine their own path of discharge in some other direction, and in which the insulation is not equal to restrain them, then discharge ensues in that direction; and its course will be determined through a line or lines in which there is the least resistance, that is to say, in which there is the least amount of insulating power: thus, if a coated pane or jar, charged to a high intensity, be so circumstanced as to discharge, as it were, through a fortuitous circuit of electrics and conductors more or less perfect, the discharge will find out for itself a path of least resistance, seizing upon some bodies and avoiding others, according as such bodies happened to be convenient, or in any way useful in facilitating its progress,—a result arising as a necessary consequence out of the principle of induction, which ranges the tension (120) in a determinate way throughout the whole line or lines of discharge, and by exalting the electrical state of the particles in that line or lines beyond the tension of the adjacent particles, determines the course of the action; and this it is which gives to electrical discharge, as it were, a sort of foresight, or faculty of perception, of the easiest course to be followed.

The following are instructive and important mechanical illustrations of this result:

Exp. 50. Let some detached fragments of leaf gold, *a b c d*, &c., A, fig. 56, be laid down on paper in any casual and convenient

way, producing with the paper a detached series of bad and good conductors: charge about 10 square feet of coated glass, and having placed the extremes P N of the series between the wires of the universal discharger (76), allow the charge of the battery to find its path across the interrupted circuit: the result will be as represented in fig. 56, B. Portions of the leaf gold, unable to withstand the disruptive effect of the shock, will be burned up, thereby showing the course of the discharge; and it will be perceived by the black portions in the figure, copied from an actual experiment, that the line of inductive force P *b d e f g h* N is the least resisting line between the points P N. It is here remarkable that not only are the fragments *c k* untouched, being, from their relative position, of no use in facilitating the progress of discharge, but even portions of the remaining pieces are also left out, and we have only the pieces *h* N totally destroyed, as being in all their parts completely essential to the course of the induction.

Fig. 56.



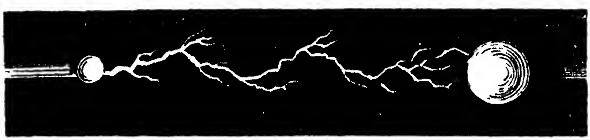
123. The distance through which disruptive discharge is obtained, as between two discharging balls or other conductors, has been called the *striking distance*. This striking distance, or length of spark, is very variable and very dependent, not only on the intensity of the charge, but on the form of the conducting bodies: the larger the conductors, the greater the electrical charge required to pass through a given distance; for in this case, as before remarked, the intensity is diminished in the inverse ratio of the square of the surface (114). Now it is by exalting the intensity of the discharging point that the greatest length of spark is obtained: sparks from electrical

machines are obtained of 10 inches or a foot in length, in rapid succession, amounting to a current. In this case it is usual to affix a ball of about 2 inches in diameter to the conductor, so as to project 3 or 4 inches from it, and then to present a large ball to this, either connected with the earth or with the opposite conductor. By crowding, as it were, upon the small ball the inductive influence of the large ball, all the lines of which terminate upon it, and at the same time collecting upon this ball, as a point of discharge, a large proportion of the electricity of the conductor, the intensity of the small ball is greatly exalted, and it strikes through a longer distance, producing, by the resisting intervening air, a crooked or zig-zag spark. The striking distance of the electrical discharge in the case of a single electrical jar is usually confined to extreme distances of about an inch: by the peculiar arrangement, however, of a series of jars in the way shown in fig. 36 (66), a long striking distance is obtained between the outer coating of the last jar and the knob of the first. Dove, at a meeting of the Royal Academy of Sciences at Berlin, in June, 1847, showed that the length of the spark by this succession of positive and negative surfaces varies with the square of the number of jars. Mr. I. Baggs, also, in a communication to the Royal Society, in January, 1848, describes a method of charging and placing the jars by which a disruptive spark of unusual length and brilliancy is easily produced. In this experiment the jars are each charged separately and to the same intensity, then quickly placed in series of positive and negative surfaces, very near, but not so as to touch.

124. The character of these disruptive sparks or flashes depends almost entirely on the form, area, and electrical intensity of the discharging surfaces, as also on the kind of electricity on the conductor in which the spark originates. If we present a large smooth uninsulated metallic ball, of about 3 or 4 inches in diameter, to the rounded prime conductor of a powerful electrical machine,—short, brilliant, and perfectly straight sparks will pass between them, accompanied by a

sharp snapping sound, but the ball must be brought near the conductor. If the same ball be presented to the negative conductor, the sparks will be far less powerful and dense; they will become small and of a pointed character. If we now attach a smaller ball to the prime conductor, of about an inch or a little more in diameter, allowing it to project about 3 inches into the air, and present the large ball to this, much longer sparks are obtained, but less brilliant than before, and of a crooked or zig-zag form. In transferring this experiment to the negative conductor, the length of the spark is very considerably diminished; frequently it will not be above one-sixth of the length. Long sparks produced from the prime conductor in this way, or by the arrangement of jars just described, will be a foot or more in length: they are attended by lateral branches or divergences, frequently of a violet colour, presenting to the eye an extremely beautiful appearance. The annexed fig. 57 may be taken to represent this kind of dis-

Fig. 57.



ruptive spark, and which, especially in the long discharge by a series of jars, is very imitative of what has been termed *forked lightning*.

Electrical sparks are more brilliant between good conductors than between imperfect or less perfect conductors: hence metals are almost exclusively employed in cases where long or brilliant short sparks are required. It has been proved both theoretically and experimentally that the actual force in operation between the discharging surfaces at the instant of disruption is the same for all distances (117); the influence of distance is only to vary the quantity of electricity requisite to produce a given force equivalent to cause a disruptive spark at

that distance, but it does not affect the actual force at the instant of discharge.

125. *Influence of pointed bodies, and action of points in modifying disruptive discharge.*—When we continue to diminish the extent of surface originating a disruptive spark, and finally arrive at a small termination or point projecting freely into the air, most important and very curious results ensue: instead of a brilliant explosion, stars and brushes of light appear to arise or settle on the points, attended by currents of wind, whilst the distance at which very small balls or points are observed to be affected is in many cases considerable: thus, in the instance of the great machine at Haarlem (48), a point appeared luminous at the distance of 28 feet from the conductor. If a short brass rod with a rounded end project from the prime conductor of a powerful machine, it will send out a full brush of luminous electrical rays, especially on presenting to it a flat imperfect conductor; and if a small ball be substituted for this projecting point, its surface, if the machine be powerful, will present a sort of phosphorescent luminous glow, apparently covering the whole surface. Faraday considers both these phenomena as variations of disruptive discharge, and has not inaptly termed one, *brush* discharge, the other, *glow* discharge.

126. Although both brush and glow discharge have been pretty nearly identified as to cause, and as being derived from the same electrical source, yet under ordinary circumstances they are in appearance totally distinct, and have a striking relation to the kind of electricity producing them: thus, according to the Franklinian theory, when electricity passes off a point, it is generally productive of brush discharge. When received on a point, the appearance is that of a glow or star or pencil of light.

Brush discharge commences, as in the annexed figure 58, in a short conical brush root, which terminates in pale quivering ramifications, attended, when the discharge is powerful, by a subdued roaring sound: this has been shown by Wheatstone to be due to a number of small distinct

Fig. 58.

and successive explosions: they may be considered as an intermitting series of short sparks between metal and air, or between any good and bad conductor. The discharge always commences at the root of the brush, and is complete at the point of the conductor before more distant particles of air arrive at the same degree of tension: hence the discharge is progressive.

Glow discharge, on the contrary, is a more quiet and almost perfectly continuous result, depending on the charging of portions of air in contact with the surface of discharge. By diminishing the pressure, the glow can be caused to pervade a large extent of surface. Brass balls of 2 inches in diameter will become covered with a luminous glow when exposed to the action of a powerful machine under a reduced atmospheric pressure of about 5 inches of the mercurial gauge. The essential difference between brush and glow discharge appears to be in the kind of action upon the particles of the dielectric medium. In the brush discharge, these particles are operated on by a momentary intermitting action, whereas the glow is a constant renewal or permanence of the same action without stop. In either case the particles of the air or other dielectric in contact with the conducting surface continue to be charged, their electric tension being highly raised. We may by certain artificial arrangements convert the one into the other: any circumstance which tends to facilitate the charge of the air, and preserve at the same time the degree of tension of the dielectric particles, produces glow; whereas by resisting the charge of the particles so as to favour previous accumulation, and a consequent sinking of tension by discharge, we produce intermissions or brush;—thus rarefaction of the air, or the presentation of a pointed conductor, favours *glow;* whereas condensation of the air, and the presentation of large surfaces, will convert the glow into a brush.

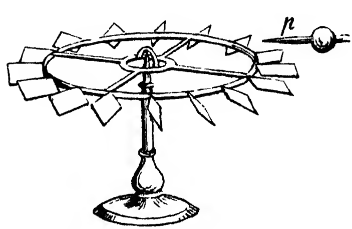
127. Franklin first noticed the influence of pointed con-

ductors on electrically charged bodies; he showed, that when presented to them, their charges became dissipated even at considerable distances, and with surprising rapidity. He charged an iron shot about 4 inches in diameter, and observed that on presenting to it an uninsulated pointed needle, its attractive force on a small thread immediately ceased. He further observed that this influence of pointed bodies was also exerted when projecting from the charged body itself: the charge became rapidly dissipated by the projecting point; at the same time a current of aerial particles set off from the point, capable of impressing motion upon light models moveable upon a central axis, and fitted with vanes. This current has been termed the *electrical aura* or gale. The re-active force of this current upon the point itself, and from which it appears to flow, is so great as to give the point motion in a reverse direction when free to move. The following experiments are very illustrative of these curious and important facts.

Exp. 51. Place an uninsulated metallic ball within about 2 inches of the prime conductor of an electrical machine, and whilst a series of strong sparks continues to pass upon it, present a pointed wire to the conductor; the sparks will instantly cease, even when the point is at more than twice the distance of the ball from the conductor, where it will in the dark appear as a star of light.

Exp. 52. Attach the pointed wire to the prime conductor itself; sparks can be no longer obtained upon the uninsulated ball, whilst a divided brush of rays will appear to issue from it, and the electrical effect will be transmitted to a point at a still greater distance.

Fig. 59.

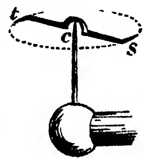


Exp. 53. Fix a series of card-paper vanes on the circumference of a light wheel, as in fig. 59; poise the wheel on a central point, and expose the vanes, which should

be set a little oblique to the plane of the wheel, to a current of electrified air proceeding from a charged point *p*, projecting either from the positive or negative conductor of an electrical machine. When the machine is set in motion, the poised wheel will turn upon its centre.

Exp. 54. Bend the extremities of a light pointed wire, *s c t*, fig. 60, at right angles to the wire, but in opposite directions: let the whole be poised on a central point, and placed in communication with either conductor of the electrical machine. When the machine is put in motion, the bent wire will fly round in a direction reverse to that of the points *s t*, and will appear in the dark as a ring of light, in consequence of the luminous particles of air receding from the points.

Fig. 60.



In all these experiments it is requisite that the point project freely into the air. If it be sheltered by being beneath the surface, then its electrical effect as a point ceases.

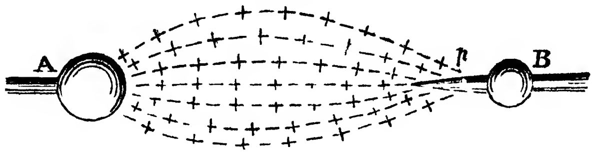
128. *Theoretical views of disruptive discharge and the action of pointed bodies.*—In the theory of induction (99) it is assumed that the particles of the dielectric are in a certain state of tension which rises higher and higher in each particle as the induction is raised higher and higher, either by the closer approximation of the inducing surfaces, increase of the charge, or variation of form, &c.: the sustaining of this tension constitutes insulation; and when the tension surpasses the insulating power, the grand close of the existing phenomena is disruptive discharge. According to Faraday, the peculiar condition of the molecules of the dielectric necessary to the induction and insulation is equally essential to the final phenomena of discharge by disruption of the intervening dielectric medium. The theory does not assume that *all* the particles are equally affected as to tension; discharge occurs not when *all* the particles have attained a certain tension, but when the tension of a particular particle upon which the whole

of the equilibrium depends has been pressed beyond endurance, and hence gives way (117): all the particles in this case must give way also; because, being all associated in the induction, it is the sum of the whole resistance which constitutes the equivalent insulation. Such is in fact the case in discharge between the balls of Lane's electrometer (91); the disruption first occurs between the two near points (117).

129. The spark-striking distance will therefore be dependent on the discharge of a few particles of the dielectric occupying a very limited space, in consequence of which the polarized inductive state of the whole series is lowered, and the molecules return to their previous or normal condition in the inverse order in which they left it (99); whilst their powers to propagate or continue the *discharging* operation from the point where the subversion of the insulation first occurred become now united. A good mechanical illustration of this may be derived by standing a series of thin rectangular pieces of wood upright, and near each other: if we overturn one at the end, the next, the next, and so on, must follow, and each in succession becomes pressed upon by the forces of all the preceding, which now unite to complete the downfall of the whole series in a given direction. The few particles originating the discharge are generally next one of the terminating conductors: in this point of subversion, however, they are not merely pushed aside, but they assume for the time an extreme tension, and the powers discharge throughout the series with violence and explosive force: the ultimate effect is the same as if we had put a discharging wire in place of the dielectric particles, and operated by conduction immediately between the limiting conducting surfaces A B, fig. 49. The tension of the particles of the dielectric next the points in the limiting conductors being greater than those in the middle of the series, it is hence in these points that the disruptive effect commences; so that when these conductors terminate in mere points or small surfaces, the tension upon the particles of the dielectric in contact with them is excessively increased; in fact, all the lines of inductive

force may be supposed to concentrate upon a pointed conducting body, thus: let A, fig. 61, be the terminating spherical

Fig. 61.



surface of an uninsulated conductor, and *p* a point projecting from an opposed charged conductor B; then the lines of inductive force will concentrate, as it were, upon the point *p*, as represented in the figure: the point therefore becomes the source of an active mechanical force, and preserves its predominance over the other portions of the conductor behind it by a continued discharge of the accumulated electricity: hence currents of wind arise by the recession of the charged particles of air, and which are in every way favoured by the shape and position of the rod immediately behind the point. If the point be more or less central to the walls of a room, without any more immediately opposed conductor, or be exposed to the induction of any other substance in its vicinity, still the same result ensues, since there is no distance so great as to limit the operation of this inductive action. The theory applies, by the converse of this, to an uninsulated point opposed to a charged body.

130. *Convective Discharge.*—In the production of currents by pointed conductors, the dielectric aerial particles necessarily carry away with them the electricity of the charged body, and so, by neutralizing the oppositely induced force in some other distant body, complete a discharge of the accumulated electricity. This species of discharge is not a communication of force, but a carrying away of force, as it were: the particles in this case do not remain in place,—they travel. Faraday has hence termed this species of action 'convective discharge;' and this term is applied to every case in which discharge is effected by

the transmission of electrified particles of matter, whether conducting or non-conducting.

131. *Discharge by Conduction.*—When the particles of an intervening dielectric *communicate* their forces, and lower the tension of the charged stratum, we have then discharge by conduction, or, as termed by Faraday, *conductive* discharge. This kind of power is common to all substances: the question is a mere question of time. In some substances, such as the metals, the communication of force takes place with extreme rapidity; in others, such as air, shell lac, &c., the process is difficult and slow,—so slow as to admit of such substances being considered as insulators. Conduction and insulation approach, therefore, very near each other, and arise both out of one common condition of matter. It is this kind of discharge by conduction which allows of the charge penetrating the particles of a solid dielectric, and causes in the charging and discharging of coated glass a spontaneous renewal of the charge (75).

Faraday has given very elegant practical illustrations of this kind of discharge. The substance spermaceti is found to be a dielectric through which induction can take place,—that is, its particles may become polarized; but it is also a very slow conductor, even when the electric force has travelled, as it were, through it to some distance: by communication of force from particle to particle we can, by removing the inductive or constraining power, cause it to return, as it were, upon its path, and re-appear again in its former position. This may be effected by giving two conjoined plates of spermaceti metallic coatings, one on each opposite exterior surface, and then, after charging and discharging the system, separating the plates, and examining their electrical condition. In this case, although *previously* to the separation after discharge, no kind of electrical indication could be obtained externally, yet, after the separation, one half exhibits positive electricity and the other half negative electricity; so that on removal from each other's *inductive* influence, the two forces re-appear upon the surface

under the attached coatings. The action, therefore, of an insulating dielectric, as in charged coated glass, is ultimately the same in promoting discharge as that of the wire which discharges it.

132. *Nature of Conduction.*—We obtain from these considerations some little insight into the nature of conduction and the action of conducting bodies (9). These bodies are subject to the general laws of induction through contiguous particles in common with electrics, by which they are brought into a state of tension or polarity; but being in this state, the particles communicate their forces and promote discharge so rapidly, that the state of tension or polarity vanishes as soon as induced: hence the comparative differences in insulating and conducting power, which admit of one class of substances being considered as insulators, and another class as conductors (12). All substances promote discharge by the communication of forces, but the capability of this action, in a *greater* or *lesser* degree, renders them better or worse conductors—worse or better insulators.* Thus, contrary to what might have been anticipated, insulation and conduction stand side by side as kindred phenomena.

133. The progress of electrical discharge by conduction through metallic or other substances involves the idea of velocity, and hence attempts have been made at various times to determine the rate of motion. We have already noticed (61) the early attempts of Watson and other members of the Royal Society, in 1748, to determine the velocity of the ordinary electrical discharge from coated glass, and their failure in deducing any thing like a numerical value of it. In more recent periods, however, this important question has been investigated experimentally with more success. Wheatstone, in 1834, by a beautiful and conclusive series of experiments, showed that the velocity of an electrical discharge through a wire of half a mile in length was at the rate of 576,000 miles in a second of time. This fact was deduced by catching in a mirror, whilst revolving

* Faraday's 'Electrical Researches.'

on a horizontal axis at the rate of 800 times in a second, three electrical sparks produced by the discharge of an electrical jar in an interrupted circuit, the interruptions being at each end and in the middle of the conducting wire. Now it was observable that the centre spark fell out of the line of the other sparks by half a degree of the circle, and had hence experienced retardation, from which it was not difficult to compute the time of discharge through the wire; for the angular motion of the image being by an optical law double that of the mirror, the time of motion through half a degree is given, when the time of a whole revolution is known. By this process it was found that the centre spark occurred later than the others by at least the one-millionth part of a second; it was nearly the 1,152,000th part of a second, giving a velocity of about 576,000 miles in a second, supposing the current to have passed from one end of the wire to the other, or 288,000 miles, supposing it to have traversed one-half the wire.

VI.

AGENCIES OF ELECTRICITY.

Mechanical Effects—Agency of Electricity in evolving Light and Heat—Luminous and Phosphorescent Effects—Chemical Agency—Electrical Currents—Magnetic Agency.

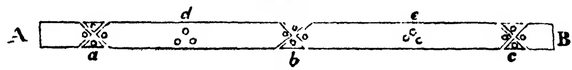
134. *Mechanical Agency.*—The transmission of electricity through substances is commonly attended by some mechanical effect: this is most apparent when the electrical discharge pervades bad and imperfect conductors; such bodies are not unfrequently rent in pieces; even good conductors, such as the metals, suffer expansion and other mechanical action to a considerable amount. If a heavy discharge be thrown upon a small metallic wire, it will become crippled, as it were, throughout its length; and when a similar discharge is passed through a capillary tube containing mercury, the tube will be shattered, so great is the expansive force of the metal. In the passage of electricity through imperfect conductors, the particles become separated by expansion, causing a compression of surrounding particles. It is this which by the collapse of the air causes the sharp snapping sound of the electric spark, and which, in the discharges of a powerful battery, amounts to a stunning report.

When the electrical discharge is less sudden and condensed, a more progressive action ensues, and these violent effects become subdued, as we have seen in the case of glow and brush discharge, and the production of currents of wind (127); whilst in the conductive discharge by metallic bodies of large dimensions, as compared with the quantity of electricity transmitted, mechanical action is no longer apparent.

The following experiments are highly instructive, and illustrative of the mechanical agency of electricity in bad and imperfect conductors.

Exp. 55. A slip of tin-foil, A B, fig. 62, about 18 inches in length and half an inch wide, is attached by a little paste to

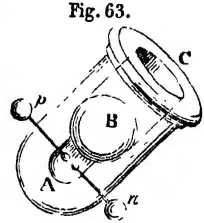
Fig. 62.



the surface of a dry piece of wood, and small cross cuts *a b c* are made on it with a sharp-edged knife; a few common wafers are placed over these cuts, and other wafers *d e* immediately between them on the continuous portions of the metal. When an electrical shock from a charged jar is passed from A to B, the small wafers will be thrown with violence off the disjointed portions *a b c* of the metal, whilst those on the continuous parts will remain undisturbed.

Exp. 56. A C, fig. 63, is a small mortar, turned out of hard wood or ivory, having two wires *p n* passed air-tight through the sides of the chamber A, and terminating in small balls placed within a short distance of each other. A ball of cork B is inserted immediately over the chamber, fitting loosely in the mortar, so as to avoid any considerable friction. When an electrical jar is discharged through *p n*, the ball B will be violently expelled in consequence of the expansion of the air in the chamber at A.

Fig. 63.



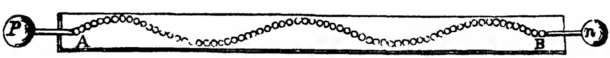
If the disruptive spark be produced within a drop of ether or water, these fluids will be converted into vapour, and the result is then more apparent: such is the expansive force thus produced, that few substances can resist it. Beccaria succeeded in fracturing to atoms a solid ball of glass of 2 inches in diameter by means of an electrical spark passed through a drop of water contained in a small cavity within the centre of the ball. Solid matter, such as stones, wood, loaf sugar, and other brittle imperfect conductors, are rent in pieces by an electrical discharge between wires placed within them.

The more progressive action of disruptive discharge through bad and imperfect conductors is frequently attended, as we have shown (125), by currents and other mechanical impulses capable of giving motion to light float wheels and other models delicately mounted on pivots.

135. *Agency of electricity in the evolution of heat and light.* —The discharge of electricity through insulating or imperfect conducting matter is invariably attended by an evolution of heat and light, to a greater or less extent. This is most apparent in the transmission of the electrical discharge through an interrupted metallic circuit, whether the circuit be continued through air or other gases, or through imperfectly conducting fluids: in air, brilliant and dazzling light arises, as in the case of the ordinary electrical spark; in water, a bright spark may also be obtained between wires placed near each other; in oil, alcohol, and ether, brilliant light is produced, attended by considerable heat. The great expansibility, however, of alcohol and ether renders experiments of this kind somewhat hazardous.

The evolution of light and heat by electrical agency admits of the following simple and elegant illustrations:

Fig. 64.



Exp. 57. Attach a series of very small circular spots of tin-foil to the surface of a strip of glass, so as to be very near each other, and forming any kind of device, as A B, fig. 64: we have thus a series of metallic interruptions, in air, immediately over a solid electrical substance: if under these circumstances a current of electricity from a powerful machine be caused to pass between the positive and negative conductors *p n*, through this interrupted circuit, it will become beautifully luminous, especially if small sparks be taken on two balls *p* and *n* connected with the metallic chain A B. In this way

very brilliant pictures in luminous sparks of dazzling brightness may be obtained by means of tin-foil pasted on glass: the foil should be divided into narrow lines or strips, cut across with a sharp knife over the outline of the picture required, and then covered with insulating varnish (29), being so connected as to admit of a conduction of electricity throughout the total length, by their alternate extremities, as represented in fig. 65. When small cuts are made in these

Fig. 65.

lines, representing any required figure, and electricity transmitted from balls *p n* at the extremities of the series, the whole figure will appear in dazzling light. Small dots of tin-foil attached in a spiral form round a tube of glass produce a brilliant effect, and may frequently be caused to extend over several feet in length: a series of metallic beads strung on a line of silk has also a singularly beautiful appearance.

Exp. 58. Insert two wires in a ball of ivory or box-wood, and pass the charge of a small Leyden jar through its centre: the ball will become for the time luminous, and appear of a crimson or scarlet colour.

Oranges, apples, and other fruits, as also eggs and sugar, may be rendered luminous in this way. The universal discharger, already described (76), is well adapted to such experiments.

136. The tendency of electricity to evolve light in interrupted circuits is such that even apparent contact does not prevent it. If the shock of a jar exposing about 4 square feet of coated glass, fully charged, be passed over a small iron chain, luminous and brilliant scintillations take place at every link of the chain, producing an extremely fine effect, especially when the chain is suspended in festoons upon insulating supports.

The heating effects of the electrical discharge are not less apparent and striking than the preceding.

Exp. 59. Fill a common wine-glass with cold water nearly to the brim, and pour on its surface a thin stratum of ether; connect the water with the prime conductor of the electrical machine by means of a wire; put the machine in action, and draw a spark from the water through the ether by means of a brass ball or by the knuckle; the ether will be immediately inflamed.

Highly rectified spirit may also be inflamed by means of a powerful spark from the electrical machine, especially if it be gently warmed and placed in a metallic cup. The electrical spark will set fire in this way to various kinds of inflammable matter, such as resin, cotton wool, phosphorus, gunpowder, and other detonating compounds, all of which may by adequate arrangements be readily inflamed.

The firing of common gunpowder by electricity is best effected by placing a glass tube full of water in the circuit, so as to diminish the violent expansive effect of the spark, by which the grains are scattered without explosion: to prevent this, the gunpowder is usually enclosed in a cartridge, and two wires inserted within it; but even then the experiment is not always successful. When the discharge is transmitted through a few inches of water contained in a tube of glass, loose gunpowder placed between the wires of the universal discharger inflames instantly.

137. The heating effects of electricity upon metals and other good conductors are also very interesting and important. We have before shown (132) that some amount of resistance to electrical transmission always takes place, even in the best conductors, which resistance may be referred to the same source as the resistance through bad conducting matter, that is to say, momentary tension and insulation: hence similar effects in the progression of electrical action through their particles.

Exp. 60. Fix a strip of silver or gold leaf on paper, and

subject it to the shock of about 8 square feet of coated glass, fully charged; the metal will disappear with a bright flash.

When a powerful shock is passed through a slender iron wire, the metal becomes heated, and may be dispersed in red-hot balls, producing in the dark an extremely brilliant effect. All the metals, when drawn into fine wire, may be caused to burn in a similar way; and the most refractory, such as platina, gold, and silver, are converted into earth-like powders of various colours, termed *oxides*.

Low degrees of heat, elicited in metals by the transmission of electricity through them, may be estimated by means of the thermo-electrometer (95). It appears from numerous experiments with this instrument, that the action of electricity in heating metallic bodies increases as the square of the quantity of electricity discharged through them, without any relation to the intensity (120) or extent of coated glass on which the charge is accumulated. This is in truth a general law of quantity, and arises out of the fact, that whatever be the extent of coated glass on which we accumulate a given quantity of electricity, or whether thick or thin, the electricity all concentrates upon the wire at the instant of discharge; and the effect is therefore quite independent of all those circumstances which influence the indications of the electrometer, and which we have so fully considered: thus, when twice the quantity of electricity is discharged, the fluid rises in the electrometer (95) to 4 times the height; with three times the quantity to 9 times the height, and so on: a law dependent very possibly on a condition of momentum, since in the discharge of a double quantity of electricity, for example, we have twice the number of particles and probably twice the velocity, which would give 4 times the force. The heating effects of electrical discharge through metals being greater, as the resistance in the wire to the progress of the discharge is greater, we may infer that the conducting power of a given metal is in some inverse ratio of the heat it evolves whilst transmitting a given electrical accumulation; and that hence by drawing vari-

ous metals into wires of a given diameter, placing them in the elcctrometer (95) and subjecting them to the force of a given accumulation (78), their relative conducting powers may be estimatad, and such is found to be the case. The following Table contains the results of a series of experiments of this kind:

Metals	Copper	Gold	Zinc	Iron	Tin	Lead
Degrees of heat	6	9	18	30	36	·72

Taking the heat of lead as unity, the following will be the relative conducting powers of these several metals, supposing the heat proportionate to the resistance:

Lead	Tin	Iron	Zinc	Gold	Copper
1	2	2·4	4	8	12

Since the resistance in the same wire may be supposed to decrease as the number of particles increase, we may conclude that the conducting power of a metallic wire will be inversely as the length, and as the area of its section directly; that is, as the square of the diameter.

138. The agency of electricity in evolving heat and light in bodies through which it passes is powerfully and wonderfully apparent in the discharge of the voltaic battery, fig. 16 (28). When an extensive series of plates, excited by an acid solution, discharges through points of charcoal, attached to stout wires connected with the opposite extremities of the battery, the heat and light evolved is most intense. With 2000 series of 4-inch plates, Sir Humphry Davy obtained an arched stream of light, of nearly 4 inches in length: fragments of diamond, on being introduced into it, disappeared; and thick wire of platina, one of the most refractory of the metals, fused readily: all the metals in thin laminæ, such as gold and silver leaf, burned vividly: when fine iron or steel wire was

made to join the opposite ends of the battery, it immediately ignited, and stout platina wire was kept at a white heat. The late lamented Professor Daniell, by his new voltaic battery, exceeded even these effects. With this battery the arc of electrical flame between points of charcoal was so intense and in such volume, that the eyes of the spectators were seriously affected and inflamed, even though guarded by thick grey glasses: the Professor's face became scorched by the heat, as when exposed to a meridian sun: the rays, when collected into a focus, burned a hole readily through paper at many feet distant, and a bar of platinum of $\frac{1}{8}$th of an inch square, together with other highly infusible metals, such as rhodium, iridium, and titanium, were easily melted. Gold leaf burned with a vivid white light, and silver leaf with a light of brilliant emerald green.

We have not sufficient knowledge of the nature of the electrical light to say on what its presence depends; but from the fact that both the light and heat attendant on electrical action vary with the resistance to discharge, it has been supposed, and with much reason, that both are evolved from the medium in which the discharge occurs, by the mechanical agency of electricity in compressing their particles—a result consequent on the same compressing effect produced in many other ways.

In condensed air the light is white and brilliant; in rarefied air it is divided and faint; in air highly rarefied it is not unfrequently of a violet colour. In a similar way the density of various gases has a material influence on the luminous effect: thus, in carbonic acid gas the light is white and vivid; in hydrogen gas, as in highly rarefied air, it is red and faint.

Electric light of great brilliancy exhibits, like the sun-light, all the prismatic colours when decomposed by the prism, and may be caused to display them separately by the intervention of different media. If a powerful discharge be passed between two wires inserted in a soft piece of deal, in the direction of the fibres, the colour of the light varies with the depth of

the points beneath the surface. If one of the points be inserted rather deeper than the other, all the prismatic colours appear. In this experiment the depth beneath the surface of the wood may be from $\frac{1}{16}$th to $\frac{3}{16}$ths of an inch.

139. *Phosphorescent effects of electricity.*—When the light evolved by the electrical discharge is very intense, a subdued luminous or phosphorescent effect continues to glow upon the surfaces of various bodies over which the discharge has passed. Calcined oyster-shells exhibit this effect in a high degree: selenite shines for a few seconds with a bright green light, and calcareous spar remains luminous.

The substances employed in these experiments should be placed between the wires of the universal discharger (79), and the eyes closed at the instant of discharge, so as to avoid the dazzling light of the spark. The luminous glow left on the surface of common chalk thus treated affords a beautiful illustration of the phosphorescent effects of electricity.

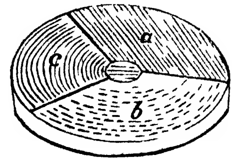
Exp. 61. Place a flat piece of dry chalk on the universal discharger, and set the pointed wires on its surface, two inches apart; discharge a large electrical jar, fully charged, through the wires; a streak of light will remain on the chalk, which will continue for some time.

The particles of brittle substances, such as loaf sugar, when dispersed by a powerful shock, appear luminous for many seconds.

140. In all these and the preceding experiments, the duration of the immediate light of the spark is very limited and transient. Wheatstone, by viewing the reflection of electrical sparks in his revolving mirror (133),* has clearly shown that the duration of the light does not exceed the one-millionth part of a second, so that objects in extremely rapid motion are seen by this evanescent light as if fixed and at rest. In evidence of this he has given the following very elegant experiment.

Exp. 62. A plane circular disc, fig. 66, having the three primitive colours,—yellow, red, and blue,—painted on it, and

Fig. 66.



occupying three proportionate sections of the disc *a b c*, was caused to revolve on a centre with great velocity, so that the colours, by an optical result, blended nearly into white, and were hence quite undistinguishable. The room being darkened, and the light of a spark from an electrical jar allowed to fall on the disc, the three colours were as apparent at the instant as if the disc were at rest. The light had in fact been produced, and had again vanished before either of the colours had turned through a sensible space. The most rapid motion, therefore, producible by art is virtually rest, when taken in relation to the velocity of the electric light.

A very effective experiment may be made with a similar disc by merely placing on it three spots,—blue, red, and yellow,—one inside the other, and which, when the disc is caused to revolve, form three distinct circles. Now, however rapid the motion, the spots are seen, by the light of the electric spark, as being perfectly at rest; and if successive sparks be produced, they appear to be merely changing their relative position on the disc.

141. *Chemical agency of electricity.*—The agency of electricity in effecting chemical changes will be found of still greater extent and importance than its mere mechanical action, although probably intimately associated with it. Not only are the most refractory metals converted into oxides, but oxides already formed may be decomposed, and the metal revived and restored to its former condition. When a succession of small electrical shocks is passed through oxides of tin, placed within a clean tube of glass, the tube becomes stained with metallic tin. If we subject common vermilion, a compound of sulphur and mercury, to the charge of a moderate-sized jar, the mercury is easily reproduced in its metallic state. When the electrical spark is taken in various fluids, the fluids may be decomposed and separated into their constituent ele-

ments. Thus water, by the action of the electric spark, may be converted into hydrogen and oxygen gases. This very important fact was first announced by some Dutch chemists, and was subsequently confirmed by one of the most distinguished of British philosophers, Dr. Wollaston. Compound gaseous bodies, likewise, are chemically acted on in a similar way: thus it was observed by Priestley and Cavendish, that when a portion of common air was exposed for a considerable time to a succession of small electrical discharges, the bulk of the air became diminished, and its constituents, oxygen and nitrogen, combined in the proportions required to produce nitric acid, which was accordingly found in the vessel in which the air was confined.

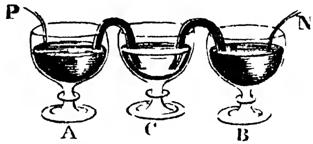
142. The most powerful and available source, however, of this electro-chemical agency is found in the series of Volta already referred to, fig. 16 (28). When substances are subjected to the continuous electrical discharge of this apparatus, very few compounds resist its power. As a general law of the decomposing agency, it is found that oxygen and its compounds, acids, &c., are determined upon the zinc or positive end of the series; alkalis, hydrogen and other inflammable matter, upon the copper or negative end. Alkalis being thus found determined to the negative extremity, were suspected by Davy to contain an inflammable element, and he finally succeeded in realizing this conjecture: by means of a powerful series, potassa and soda were resolved into two constituent elements, viz. oxygen gas, which appeared at the zinc extremity, and a highly inflammable kind of metal, which was rendered up at the copper or negative extremity,—a discovery which shed an extraordinary degree of lustre on British Chemistry.

In the electricity of the voltaic battery, therefore, we possess a most powerful chemical agency, by which the elements of bodies may be separated and transferred to distant points. The following experiment is another fine example of this important fact.

Exp. 63. In the centre glass C of the three glass vessels

A C B, fig. 67, is a solution of sulphate of potassa, one of the neutral salts: A and B contain a light infusion of the blue cabbage in distilled water, which is highly sensible of the presence of alkali, or acid, its colour being immediately affected thereby: the three glasses are connected by filaments of moistened cotton, as shown in the figure

Fig. 67.



and the wires P N from the opposite ends of the voltaic series, terminating in gold or platina points, inserted in the glasses A B. The result is, that the neutral salt in the glass C is soon decomposed into potassa and sulphuric acid: the acid is transferred to the positive cup A, and turns the blue infusion red, whilst the alkali becomes transferred to the negative cup B, and turns the blue infusion green.

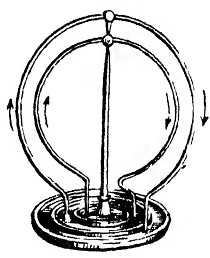
When metallic salts are subjected to this species of electrical action, they are speedily decomposed and the metal revived: thus a plate of silver connected with the negative wire of the battery will, when plunged into a solution of sulphate of copper (blue vitriol), become coated with metallic copper directly we immerse the positive wire P in the solution.

143. *Electrical Currents.*—Another important agency of electricity consists in its progressive, or, as it is usually termed, current action, as exhibited in the phenomena of conduction and discharge. When we discharge an excited voltaic series, or an electric jar, through any substance, whether metallic, moist conductors, or air or other elastic media, this progressive or current force always arises, and the substances transmitting the electricity exhibit extraordinary and very peculiar powers. Now it is an important feature of an electrical current, that the two electrical forces are every where in it; the current is in respect of these forces the same in every part: we have never a current of one force only, so that, as stated by Faraday, it is quite indivisible, and may be conceived of as an axis of power in every part of which the

two forces are present. Electricity as a chemical agent appears to operate directly through the medium of this current force. Thus in the decomposition of water and other bodies an electrical current is established, sufficiently powerful to separate the constituent elements which then interchange the two forces, and operate in lowering the tension by a species of convective discharge. The fluid, whilst under the influence of the battery, may be considered as any other dielectric substance in a state of tension (120). Faraday has termed such substances as decompose in this way *electrolytes*. The determining action, he further shows, exists within them, and not at the poles or doors of the battery; the chemical force of the current being directly as the quantity of electricity transmitted.

About the year 1820, the celebrated French philosopher Ampère discovered the mutual attractions and repulsions of electrical currents, and showed that metallic wires, if free to move, attract each other when transmitting electrical currents in the same direction, and repel each other when the currents passing through them are in opposite directions. When two wire rings are freely suspended one over the other, as in fig. 68, so as to turn readily in a vertical plane, and electrical currents transmitted through them, through the intervention of a little mercury in which their extremities terminate, the rings will be observed to separate and turn round upon their pivots until the currents passing through them flow in the same direction. Faraday has since shown that wires transmitting electrical currents induce momentary currents in other wires near them: thus the phenomena of attraction, repulsion, and induction are common both to statical and dynamical electricity, that is to say, to electricity both at rest and in motion.

Fig. 68.



144. *Magnetic agency of electricity.*—The agency of electricity in imparting polarity to iron and steel was observed by

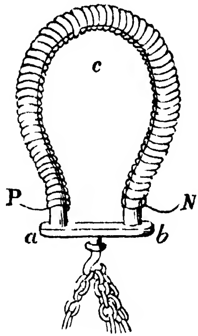
Franklin, and further verified by Van Marum with the great machine and battery in the Teylerian Museum at Haarlem (48). By this apparatus, pieces of watch-spring 6 inches in length were rendered powerfully magnetic: when the discharge was passed through the steel placed perpendicularly, the lower end acquired a north polarity, that is to say, if suspended in a horizontal position, that end pointed to the north; if placed horizontally in the magnetic meridian, the end pointing north acquired a north polarity, whichever extremity was connected with the negative side of the battery.

The most important discovery, however, in this department of Electricity is of comparatively recent date. This discovery, one of the greatest of modern times, is due to Professor Œrsted, of Copenhagen, who was led, about the year 1819, to investigate the peculiar condition of a wire uniting the terminating plates of the voltaic battery, so as to form a closed circuit. The magnetic needle, when placed above or below this wire, termed by Œrsted a conjunctive wire, immediately deviates from its meridian according to certain laws, and tends to place itself at right angles to the wire. In all these deviations the pole of the needle over which the negative electricity enters turns towards the west, and the pole under which it enters turns towards the east. On further investigation, it appears that the transmission of the electrical current through the wire is attended by a transverse action exerted in a direction at right angles to the direction of the current, which action is always the same in kind and direction: this force in relation to current electricity is what lateral tension is to statical electricity (120). The distinguished French philosopher Ampère was amongst the first to pursue these new inquiries, and he succeeded in imparting to wires transmitting electrical currents all the properties of common magnets.

145. One of the most surprising results of the magnetic agency of electricity is the enormous power induced in soft iron by the circulation of electrical currents about its surface.

Exp. 64. Let *a c b*, fig. 69, be a cylindrical bar of soft iron, bent so as to bring the extremities *a b* near each other, and P and N copper wire covered with silk thread wound round its surface from P to N; then, on uniting the extremities P N of this coil with the terminating plates of a voltaic battery, the iron immediately becomes magnetic, and will sustain by attraction at its extremities *a b* a considerable weight when affixed to a square iron rod, joining the extremities or induced poles *a b*.

Fig. 69.



By superposing heliacal coils in this way upon the surface of a soft iron bar, and uniting the extremities into one common terminator P N on each side, temporary magnets have been produced capable of sustaining more than a ton weight; the magnetic power, however, is lost, or nearly so, directly the currents cease to circulate through the coils.

The magnetic, as in the case of the chemical and heating agency of electricity, is, *cæteris paribus*, directly as the quantity of electricity transmitted, without reference to the intensity.

By the operation of these powers, and the peculiar kind of tangential force they display, electrified wires and magnets are caused to revolve round each other, and a vast variety of most interesting and wonderful effects obtained, constituting a most beautiful department of science, termed *electro-magnetism*.

146. *Magneto-electricity.*—Magnetism having been thus found to arise out of electrical action, the conclusion was irresistible, that electricity should also be derived from magnetism. Although this conclusion lay dormant for several years, it was finally completely verified by Faraday in the course of the year 1831, being about twelve years subsequent

to Œrsted's celebrated discovery (144). When a piece of soft iron surrounded by coils of copper wire is brought into or removed from contact with the poles of a magnet, electrical currents are produced in the wire of considerable magnitude, as shown in the action of the magneto-electrical machine, fig. 17 (28). Hence has arisen a new and most valuable branch of electrical science, termed *magneto-electricity*, the essential principle of which consists in the converse operation of magnets, either permanent or temporarily produced in the common electricity of non-magnetic bodies.

The following is a remarkably elegant experimental illustration of magnetism induced by electricity, and the simultaneous and reciprocal excitation of electricity by the induced magnetism.

Exp. 65. Let copper wire, covered with silk thread, be wound round opposite semicircles of a soft iron ring of about 6 inches in diameter, leaving a separating portion of the iron between the coils; then, if the extremities of one of the coils be connected with the voltaic battery, fig. 16 (28), a current is established through that coil which magnetizes the iron beneath. At this instant a current of electricity arises in the coil on the opposite semicircle by the flow of magnetism through the ring, and which, if the battery be sufficiently powerful, will cause a spark to appear between the extremities of this coil, if duly placed near each other, fig. 17 (28), and will exhibit other electro-magnetic effects. It is, however, to be observed that this action is temporary, as in the case of the magneto-electric machine (28), and exists only at the instant of making or breaking the contact of the opposite coil with the voltaic battery.

VII.

NATURAL ELECTRICITY.

Electricity of the Atmosphere—Lightning and Thunder—Meteors—Aurora Borealis—Water-spouts—Whirlwinds and Earthquakes.

147. *Electricity of the Atmosphere.*—Electrical science, in the early periods of its history, appears to have been limited to the phenomena of attraction and repulsion developed in certain bodies, by exciting into action some curious and hidden principle which such bodies were supposed to contain. No sooner, however, had the brilliant discoveries of the eighteenth century been achieved, than a far wider and apparently unlimited field of investigation presented itself. Electricity now became associated with those great and mysterious agencies upon which the natural operations of the material universe were supposed to depend. Dr. Wall, who, in the year 1705, observed the light, together with the crackling sound attendant on electrical excitation, became impressed with its miniature resemblance to the phenomena of lightning and thunder. Grey observes (Philosophical Transactions, 1735), that the electrical fire seems to be of the same nature with thunder and lightning. The Abbé Nollet, in 1745, speaks of "thunder and lightning being in the hands of Nature what electricity is in ours," and speculates on the probability of a thunder-cloud being an "electrified body, depending on the same mechanism as that of charged conductors." The great discovery of the Leyden phial, and the several investigations of Franklin, especially those relative to the action of pointed bodies, went still further in confirmation of these conjectures, and in the association of various luminous phenomena of the atmosphere with ordinary electrical action. Watson, in the 48th volume of the

Philosophical Transactions, enumerates certain appearances recorded by the ancients, evidently depending on electricity in the air. Pliny tells us in his Natural History, that stars settle with an audible sound on the sail-yards of ships. Seneca describes the spears of the soldiers in the Roman camp as being on fire. The old historian, Herodotus, states that the Thracians disarmed the heavens of their thunder by launching their arrows into the air. Such phenomena are evidently nothing more than natural interpretations of the action of pointed bodies, and of certain forms of disruptive discharge (121), (125). Important coincidences of this kind could not fail to arrest the attention of those distinguished men who, about the middle of the eighteenth century, had surprised mankind by their great and novel discoveries in electricity, and to convince them of the prevalence of electrical agency in the ordinary operations of Nature.

148. In the year 1749, Franklin proposed two methods for obtaining electricity from the clouds; and at his suggestion, in 1752, an insulated pointed rod of iron, 40 feet long, was erected by Dalibard, at Marley la Ville, near Paris, so as to project freely into the air. On the 10th May, 1752, electrical sparks were obtained from this rod, attended by the usual snapping sound. Franklin having noticed the great similarity between lightning and the ordinary electrical discharge, suggested the employment of pointed conductors in this way, for collecting electricity from the clouds and air. Lightning, he observes, is generally crooked and waving; it strikes the most prominent bodies, takes the readiest conductor, sets fire to inflammable matter, rends bodies in pieces, destroys animal life, and affects the magnetic needle; all of which are likewise effects of the ordinary electrical battery. His conviction, therefore, of the identity of the agency of lightning with that of common electricity amounted in his own mind to a reality. Tired of waiting for the erection of a tall spire in Philadelphia, upon which he had proposed to place a pointed conductor, this distinguished philosopher, in June, 1752, found

a readier access into the higher regions of the air by means of a common kite. The kite had a pointed wire affixed to it, whilst the line of the kite was insulated by a silk cord connected with its lower end, and which terminated in a common key, thus made subservient to the purposes of an insulated conductor. After patiently awaiting the passage of several clouds over the kite, he had the unspeakable delight to observe some of the loose fibres of the hemp string bristle upwards and repulse each other (16); and finally, as the conducting power of the string became increased by the fall of rain on it (9), electrical sparks were drawn from the insulated key placed at the extremity of the string. Thus became realized, by actual experiment, one of the most beautiful and important discoveries in the history of science. Romas, in France, repeated Franklin's experiments, and, as stated by the Academy, according to an original conception of his own. In June, 1753, he raised a kite 550 feet into the air during the prevalence of thunder-clouds; the string had a copper wire round it, and was attached below to an insulated iron tube. The effects not only astonished but greatly endangered the spectators; flashes of fire, a foot long and 3 inches wide, passed from the insulated conductor communicating with the string, attended by loud reports heard at a distance of 500 feet, and produced the sensation of the spider's web upon the faces of the spectators (48). Three straws, one of them a foot in length, were observed standing erect upon the ground towards the string: these at last began to dance up and down (13). At this instant a roaring noise ensued, similar to that of a forge bellows; the large straws now became violently attracted and repelled by the insulated tube, and three distinct, ringing, sharp reports ensued, similar to the sound of earthen jars dashed in pieces on a stone pavement. A spindle-shaped flash accompanied each of these discharges; the long straw now began to follow up the kite string with extreme rapidity, being sometimes attracted and sometimes repelled: it ascended in this way about 300 feet; the kite itself appeared

as if surrounded by a luminous cylinder 3 or 4 inches in diameter.

A celebrated Russian, Professor Richman, of St. Petersburg, lost his life whilst prosecuting similar experiments. Having erected an insulated or pointed iron rod on the top of his house, he hastened there from the Academy of Sciences, in August, 1753, to observe the amount of charge communicated to a large quadrant electrometer (81) connected with the rod. At this instant, whilst stooping to examine the index, a large globe of bluish fire struck him on the head, and he instantly expired.

149. Saussure and other celebrated philosophers have subsequently made extensive experiments on the electricity of the atmosphere, and have shown that the air is generally more or less charged with electricity, either positively or negatively. This may be the case, and to a considerable extent, even under a serene and clear sky, as appears by the following highly valuable notice of certain electrical phenomena of the atmosphere, by General Pollock, whilst commanding a division of the British army in India, stationed at the fort of the Himalayan Mountains, about 40 miles from the Khyber Pass, —the soil a vast plain of sand. About the end of April, 1842, the air being quite clear, not a cloud in the sky, the musket of a European soldier on duty having on it a fixed bayonet, became so powerfully charged with electricity as to emit a succession of electrical sparks from the barrel, whenever any conducting body was presented to it. General Pollock himself drew from it by means of the knuckle several powerful sparks of electricity. The musket was supported upright on the hand in the usual way of soldiers on duty. The stock of the musket was made of a peculiar Indian wood from the Sipoo tree, and which was sufficiently non-conducting to insulate the barrel and other parts of the musket above the hand.*

* Communicated by General Pollock to Mr. Grant Dalrymple.

150. Our talented countryman, Mr. Crosse, of Bromfield, near Taunton, in Somersetshire, has greatly contributed to our knowledge of atmospheric electricity, and has elicited some very important and general facts. His apparatus consists of more than a mile of insulated wire, extended between pointed conductors raised high into the air upon tall masts upwards of 100 feet in length. It appears, by experiments with this apparatus, that the electricity of the atmosphere has a daily flowing and ebbing period, like the sea, being found to increase and decrease in force twice every 24 hours. Generally, the electricity obtained from the air is positive, especially in clear weather; but during the fall of rain, fogs, snow, and storms, and especially during the passage of certain clouds, the apparatus is frequently electrified negatively. We are also in possession of numerous valuable observations made at the Kew Observatory by Mr. Ronalds, for the British Association. We are indebted to Mr. Ronalds for a high perfection of the means of observation, and, together with Mr. Crosse, for the following general results:

1. The electricity of the air is always positive,—increases after sunrise, diminishes towards noon,—increases again towards sunset,—and then decreases towards night,—after which it again increases.

2. The electrical state of the apparatus is disturbed by fogs, rain, hail, sleet, and snow. It is negative when these first approach, and then changes frequently to positive, with subsequent continued changes every three or four minutes.

3. Clouds also, as they approach, disturb the apparatus in a similar way, and produce sparks from the insulated conductor in rapid succession, so that an explosive stream of electricity rushes to the receiving ball, which it is wise to let pass off into the earth. Similarly powerful effects frequently attend a driving fog and heavy smart rain.

151. Electricity being thus intimately associated with meteorological changes in the atmosphere, it is thus further evident that thunder, and lightning, and several other meteoric

appearances, are dependent on the ordinary operations of electrical agency. If we consider attentively the electrical conditions of a thunder-storm, we may observe in them, all the elements of the Leyden experiment: the atmosphere, in fact, becomes a great coated pane or fulminating square (63), of which the charged cloud is the insulated, and the surface of the earth the uninsulated, terminating conducting planes;—the phenomena of thunder and lightning are neither more nor less than disruptive discharges through the intervening air, on the principles we have already explained (121), the magnitude of the effect depending on the tension. It has been well observed by Franklin, "If two gun-barrels strike at two inches distance and make a loud report, at how great a distance may 10,000 acres of electrified cloud strike, and how loud must be that crack!" We may further remark, that all the causes which operate in modifying the phenomena of the common electrified spark, also operate in giving variety to the phenomena of lightning. Thus lightning is often waving, or of a crooked zig-zag appearance; at other times it is straight and brilliant: when occurring near the observer, the light is quite intolerable to the eye. Sailors are accustomed to call the dividing zig-zag spark 'forked lightning:' when it does not divide, it often affects the eye by a sort of ripple of light,—this they term 'chain lightning:' when a vivid sparks occurs, but concealed from the eye by interposed masses of clouds, the light is so reflected from more distant masses as to illuminate the whole of the hemisphere,—this has been termed 'sheet lightning.' Arago, however, and other philosophers, have given this term to electrical discharges spread out into broad alternated flashes, such as we observe in the flashes of a summer evening. The phenomenon termed 'globular lightning,' presenting an appearance of a ball of fire either in motion or at rest, is referable to glow discharge (126), which commences and proceeds for a short time previously to the more condensed disruptive discharge of the whole system. In this way balls of fire have been observed to roll along the sea and ground, or become

stationary, previously to a burst of thunder and lightning, according as the cloud upon which the discharge depends is at rest or in motion.

152. The noise called thunder may be referred to the collapse or mechanical and violent compression of the air by the disruptive discharge (121), and to the reflected or successive echoes of the sound reverberating between the opposed surfaces of clouds or land, and which has been called the roll of the thunder: thus, when a cloud covers the horizon, the noise of cannon fired at sea is often attended by a long-continued roll like thunder.

As the motion of sound is extremely slow compared with that of light, being not more than about 1000 feet in a second of time, whilst light travels at the rate of 190,000 miles in a second, we are enabled by neglecting the evanescent time of the light to calculate the distance of the point in which the disruptive discharge begins, merely by multiplying the number of seconds which elapse between the light and the sound of the thunder by 1090, the actual rate of motion of the sound in a second. Thus an interval of 5 seconds would give 5450 feet for the distance of the thunder-cloud from the observer, being rather more than a mile.

153. The effects of electrical discharge under the form of thunder and lightning are similar to those already noticed (121), the mechanical effects being of a most stupendous character. Wood and other resisting matter is rent, and scattered in all directions; nothing appears to stand against it: thus rocks are split open and scattered, and trees of enormous size, especially the oak, rent asunder. In November, 1790, the 'Elephant,' of 74 guns, was struck at Portsmouth by an electrical discharge from the atmosphere, which entirely shook and shivered her mainmast, weighing about 18 tons: all the iron hoops and mouldings were burst open and scattered around: some of the hoops were half an inch thick and 5 inches wide: the mast itself consisted of a mass of wood 3 feet in diameter and 110 feet long.

154. *Meteors.*—All those ordinary meteors found on the masts and sail-yards of ships and other pointed bodies are, without any question, pure effects of atmospheric electricity depending on the action of pointed bodies projecting into electrified air (125). These appearances have been termed by Spanish sailors the 'Fires of St. Elmo,' and in superstitious times were supposed to proceed from the body of the Saint. In the record of the second voyage of Columbus we find that "during the night of Saturday (October, 1493) Saint Elmo appeared on the top-gallant masts with seven lighted tapers." The Italians refer these appearances to St. Peter and St. Nicholas: the Portuguese call them 'Corpo Santos;' hence, probably, the term used by English sailors of 'Comazants.'* The action of electrical points may hence be adduced in explanation of many of those luminous phenomena of the atmosphere found occurring near the earth's surface. Other meteors, however, although suspected to originate in electrical action, do not appear to be so clearly referable to it. Amongst these may be classed the well-known phenomenon of the 'shooting-star:' this appearance, however, has still been successfully imitated by passing the shock of an intensely charged jar between balls enclosed within the extremities of a long glass tube exhausted of its air. In the present state of our knowledge, however, of such meteors, we cannot pretend to decide on the question of their electrical origin.

155. *Aurora Borealis.*—The magnificent phenomenon termed Aurora Borealis, or Northern Lights, may be certainly classed amongst meteors depending on ordinary electrical action, and may be referred to the flashing of electricity through air more or less rarefied, and at variable heights above the surface of the earth. If a pointed conductor be caused to discharge electricity within an exhausted glass receiver, streamers of white and coloured light, and diffuse or pervading flashes, are

* 'Tomlinson on the Thunder-storm,' published by the Committee of General Literature and Education appointed by the Society for Promoting Christian Knowledge.

produced, closely imitating the phenomenon termed Aurora Borealis. A receiver of 6 inches in diameter, and 10 feet high, appears as if filled with light under the action of a powerful electrical machine; the light and colour depending on the rarity of the air, the amount and kind of vapour it contains, and the substance and form of the conducting body from which the electricity is transmitted. By a careful management of the experiment, beautiful violet and red streamers, and splendid coruscations, together with diffuse glow, are easily obtained. By far the greater number, however, of such appearances as observed in these latitudes, may be traced to the presence of dense masses of electrical clouds yielding up electricity into the atmosphere above them. Both glow and brush discharge (126), diffuse and infinitely varied, and of a vast extent, is produced in this way, and is often observed to proceed from behind the masses of clouds in long shooting streamers, attended by a beautiful glow of diffuse light, varying from green to deep purple, violet, and red, and which sometimes covers the hemisphere. This light has often the appearance of luminous vapour, quite transparent, so that the stars are visible through it: this is also the case with the diffuse light artificially produced in an exhausted receiver, in the way just stated. Such phenomena are commonly followed by wind, rain, and unsettled weather.

In Siberia and high Northern latitudes, the meteor termed *Aurora Borealis* assumes a character of the greatest imaginable splendour. Here the electrical phenomena are most distinctly marked;—here we find beams and rays of light moving with greater or less velocity; these are termed in the Shetland isles *Merry Dancers;*—also vast columns of light, arches and crowns of various colours, the lower extremities of which frequently quiver with a fiery red colour, and the upper with orange and violet. In Siberia the aurora begins with single bright pillars, which rush about from place to place with great velocity, and finally cover the whole sky: the streamers then meet in the zenith, and appear as if covering the surface of the

earth with a vast tent of light glittering with gold, rubies, and sapphires. Brilliant luminous coruscations also frequently occur, accompanied by a crackling sound, like the crackling of sticks when fractured, and very like the ordinary sound of electrical excitation: the noise sometimes is that of a rushing hissing sound, as if the largest fire-works were in action. At this time, the dogs of the Siberian hunters are said to crouch with terror on the ground, and will not move. All these phenomena are purely electrical, and are well produced in turning round a large electrical plate, detached from the conductors of the machine.

The more early observers of the aurora supposed it to occur at very considerable elevations above the surface of the earth, in regions where the air was indefinitely rare. Euler estimated the altitude at some thousands of miles. This meteor, however, by more recent observation, certainly takes place at far less elevations above the earth than is generally supposed, and does not in any case probably reach the sensible limit of the atmosphere. Franklin, at Fort Enterprize, in February, 1821, determined the altitude of an aurora to be less than the elevation of that of denser clouds,—a fact confirmed by Parry in his third voyage. Lieutenants Sherer and Ross, who accompanied Captain Parry, were, together with Captain Ross, simultaneously surprised at seeing a bright ray of the aurora shoot down from a general mass of light in the heavens, within a distance of them less than 3000 yards.

156. *Water-spouts and Whirlwinds.*—The agencies of electricity in the production of certain atmospheric meteors has been, and not without some show of reason, extended to the phenomena of water-spouts and whirlwinds, which are supposed to arise from the operation of electrical attraction,—water-spouts at sea being what whirlwinds are on land. These have been known to tear up trees and scatter bodies in all directions, and are attended by a rumbling noise. Water-spouts have the form of a speaking-trumpet, with the broad end near the clouds. All these appearances occur in months

most liable to thunder-storms, and closely resemble what might be expected from the prolongation of protuberances of electrified clouds towards the sea, occasioning thereby a mutual attraction between the water and the clouds. These appearances are said to be dispersed by mariners by presenting to them sharp-pointed conductors.

157. *Earthquakes.*—Dr. Stukely, in some very interesting memoirs printed in the Transactions of the Royal Society for 1749 and 1750, has ingeniously referred the phenomena of earthquakes to electrical action within the earth, and endeavours to support this conjecture by reference to the vast extent and mass of earth simultaneouly shaken,—from the prevalence of electrical phenomena which attend them, such as coruscations, thunder, lightning, and fire-balls of various kinds. At the time of the great earthquake in London, in 1749, such appearances were in abundance. A sound was observed to roll from the River Thames to Temple Bar before the houses ceased to nod, as when an electrical shock is accompanied by the report of the discharge,—whilst all the mechanical phenomena correspond to the peculiar vibrating motion of disruptive discharge in the substance of imperfect conducting matter. In the concussion at Daventry, in Northamptonshire, in September, 1750, the motion was felt throughout a space of 100 miles in length and 40 in breadth, and 4000 square miles of surface were convulsed in an instant.

That a high amount of electrical action attends these wonderful operations of nature is quite certain, but in the present state of our knowledge of such phenomena, their reference to pure electrical action as a primary cause must necessarily be considered to rest on a very hypothetical basis.

VIII.

CONCLUDING REMARKS.

Practical Applications of Electricity.

158. In the foregoing pages we have been anxious to direct the reader's attention to the *principles* of electrical science rather than to its practical applications. When the principles are fairly established, practical applications are comparatively easy, and of less importance to be brought before the general reader in minute detail. In the brief remainder of our space we can only just glance at a few of the examples of *power* which electrical *knowledge* has supplied.

The first and most obvious practical result of Franklin's discoveries was the *lightning conductor* for the protection of buildings and ships from the violent effects of the disruptive discharge. The first lightning conductors consisted merely of metallic rods or chains proceeding from the highest point of the building or the ship, in a direct line to the earth or to the sea: but this was not found in all cases sufficient. Instances have occurred in which the conductors have been fused or shattered,—and hence arose a prejudice against their use, under the idea that they did more harm than good, by inviting the destruction they were intended to prevent. An attentive examination, however, of numerous cases of damage from lightning has shown that the path of discharge from the cloud to the earth is always in the line of least resistance (122). This line may not be the shortest lineal distance, but it is in all cases the shortest electrical distance; that is, the lightning picks out the best conductors in its transit to the earth, selecting with the nicest discrimination metal cramps and fastenings (122), and by its expansive power shattering and

destroying inferior conducting substances, such as wood, brick-work, and stone.

159. The discoveries of Franklin and other philosophers of the last century (147) very fully prove that what we call thunder and lightning is the result of disruptive discharge produced by a great natural electrical agency, forcing its way through resisting matter, and which, as we have just seen, is attended by irresistible expansive force with an evolution of intense light and heat (134) (135). Now this agency in finding a path through matter offering little resistance to its progress, such as the metals, is no longer productive of such disruptive effects. The explosive form of action either vanishes altogether or becomes so modified as to merge into a sort of current, traversing the metal with a greater or less degree of rapidity. If therefore a building or a ship were perfectly metallic in all its parts, no damage could possibly arise to it when struck by lightning, since the explosive action would vanish from the instant the electrical agency entered the metal. In applying lightning conductors, therefore, as a means of guarding against the destructive effects of lightning, our object should be to carry out this principle in all its generality, and bring the given building or ship as nearly as possible into that state of passive electrical resistance it would have supposing the whole mass were metallic throughout. Now this is best accomplished by connecting together, so far as possible, all the large detached masses of metal in the fabric, and between which disruptive discharge is likely to ensue (122), and then unite these with capacious conductors leading directly from certain of the highest points of the structure directly to the earth or sea. These conductors should of course be metallic, but as metals vary in conducting power, copper, being the best conductor, is to be preferred (137). It has been found that a copper rod of one inch in diameter, or an equal quantity of copper under any other form, will resist the expansive and heating effects of any discharge of lightning hitherto experienced. In applying such conduc-

tors to buildings, they should be fixed to the masonry and project into the air by sharp or pointed terminations (125); below they should terminate in two or more branches leading under the surface of the ground, and, if possible, to moist earth, drains, or springs of water. In applying such conductors to ships, each mast should have its own capacious conductor permanently fixed and connected with bands of copper passing through the sides of the ship under the deck-beams, and with the large bolts leading through the keels and keelson, and including, by other connections, all the principal metallic masses employed in the construction of the hull. Under such a system, a discharge of lightning falling on a house or a ship finds its way to the earth or to the sea without the possibility of damage.

160. Much discussion has arisen relative to the amount of security such conductors can insure when compared with the quantity of lightning, which, by their supposed attractive influence, might become drawn down upon the buildings to which they are applied: such controversies, however, are now very completely disposed of by the great natural experimental facts which have presented themselves upon this question, especially within the last twenty-five years. The notion that lightning rods draw down lightning upon a building in virtue of a specific attractive power for the agency of lightning is not only unsupported by any evidence whatever, but is positively at variance with the whole course of experience. It is now well known that metals have not *per se* any greater influence on the electrical discharge than other kinds of matter (116). Lightning will always find for itself a path of least resistance to the earth: if metallic substances be present and be convenient to its action, it will then fall on them, but not else (122); if not present, it will seize upon any other body which is convenient to it: so that metallic conductors can be no more said to attract the lightning which falls on them at the time of a thunder-storm, than a rain-pipe can be said to attract the rain which falls on a building at the moment of a shower;

the action of both is purely passive; any calculation of the radius of protection of a lightning rod, therefore, in virtue of its attractive power on the agency of lightning, will necessarily be fallacious, as is in fact shown by experience. Several cases have occurred in the Royal Navy in which one mast of a ship has been shivered by lightning, a chain conductor having been applied to the other. It is by no means uncommon to find heavy discharges of lightning strike upon the sea in the vicinity of such conductors, as if avoiding them altogether.

161. If we for a moment look at the course of experience, we can have no longer any doubt upon this question. In this country alone, the amount of damage which has occurred and still continues to occur by lightning, especially to churches, is beyond all credence. Fuller says in his 'Church History,' "that scarcely a great abbey in England exists which, once at the least, was not burned down with lightning from heaven;" and then he enumerates a great many so destroyed. In modern times we may observe similar destructive effects. Now it is notorious that in no case where such destruction has occurred has the building been provided with lightning conductors: on the contrary, no instance of damage has arisen to any building to which such conductors have been efficiently applied; the exceptions being so insignificant as not to be worthy of record. If we look at the destructive effects of lightning in ships, the results of experience are most especially interesting and conclusive. It appears from the records of the Navy, that the destructive effects of lightning on H. M. ships involved in former years an expenditure of not less than from £6000 to £10,000 annually; in 200 cases only, 300 seamen were either killed or hurt, and above 100 large masts, valued at the time at from £1000 to £1200 each, entirely ruined. Between the years 1810 and 1815, no less than thirty-five sail of the line and thirty-five frigates and smaller vessels were completely disabled. Now, since the system of lightning conductors, just described, has been fully carried out in all

H. M. ships, it appears that damage by lightning has positively vanished from the records of the Navy.

162. The following is an interesting and remarkable instance of the beneficial action of such a system of conduction as that we have adverted to, taken from the official journal of one of H. M. ships. 'The Conway,' a small frigate of 28 guns, being moored in the harbour of Port Louis, in the Isle of France, was at 11 A. M. of the morning of the 9th of March, 1846, struck by lightning. At this time the ship was under refit, the higher or top-gallant masts down on the deck, so that to support the pendant a small spar, *not having a conductor on it*, was substituted for the main top-gallant mast, being fixed at the head of the top-mast. Now the terrific flash which fell on the vessel first struck this spar, and shivered it in atoms: at the point of junction, however, with the large copper conductor on the top-mast below and leading to the sea, all further destruction ceased; the explosive action vanished, and the electrical discharge streamed safely into the water, apparently expanding upon the surface in a blaze of brilliant light. The brief notice in the ship's log runs thus: "11 . 45. Pendant staff at main topmast head shivered in pieces by lightning; conductor carried off the fluid without further damage."

163. The heating power of electricity has been turned to account in promoting the efficacy and lessening the danger of blasting on land and under water. Instead of the common fuse, as ordinarily employed, a fine wire is passed through a charge of gunpowder, properly secured, and the ends of the wire are connected with the terminal wires of a voltaic battery: the moment the circuit is completed the fine wire is ignited, and the powder explodes.

164. The lighting of public streets and buildings by voltaic electricity is an application of the voltaic battery which has occupied the minds of practical men during many years past, from the time, indeed, when Davy produced the magnificent arc of light from his large battery at the Royal Institution. So long as voltaic batteries were costly and their effects only

of short duration, this application was deemed impracticable; but when *constant* batteries, as they are called, were invented at a cheap rate, the attempts to apply the light from the charcoal points to the purposes of illumination became numerous. It is now some years since M. Archereau exhibited his splendid voltaic light in the streets of Paris, and Mr. Staite not long since dazzled the metropolis of London in a similar way. These gentlemen seem to have overcome the difficulties which prevented their predecessors from obtaining a *continuous* light. Its intensity seems eminently qualified for light-houses, railway signals, &c.

165. The constant battery invented by the late Professor Daniell has also given rise to an art which, within a very short period, rose to an eminent position among the useful arts and manufactures of this country, namely, *electro-metallurgy, electrotype, galvano-plastic*, &c. The principle upon which these arts rest is that of voltaic electricity, fig. 16 (28), but produced under the form of what has been termed the 'constant battery.' This is an arrangement of copper and zinc, but is excited by *two* fluids instead of one. The two fluids are separated by a diaphragm which prevents them from mixing, but allows the electric current to pass. There is first a rod of zinc immersed in dilute sulphuric acid contained in the porous diaphragm, surrounding which is a solution of sulphate of copper contained in a copper cell. By this arrangement the solution of zinc is kept away from the copper, and the hydrogen, instead of escaping, passes through the porous diaphragm with the current, when it combines with the oxygen of the oxide of copper in the solution of the sulphate, thereby leaving pure metallic copper, which lines the interior of the copper cell. By peculiar contrivances this copper can be made to deposit itself as fast as it is formed on moulds of wax rubbed over with black lead to give a conducting surface; or the copper can be deposited on the cylinders and rollers used in calico printing, working out the pattern with the greatest fidelity; also in surface printing, etching, and

various other applications. When the solution of some salt of gold or silver is used, instead of the solution of copper, a thin film of either of the precious metals can by voltaic action be deposited on articles and ornaments previously cast and finished in some inferior metal. In this way basket-work, fruits, leaves, flowers, busts, grapes, statues, and medallions have received coatings of copper (142) and other metals:* even Daguerreotype plates have been copied by this means. By writing on a metallic surface with a peculiar kind of varnish, and then depositing the copper over the lines, a plate fit for printing is obtained. By voltaic arrangements metals can be assayed; iron covered with thin films of lead, thereby preventing rust; pins can be tinned, and numerous other applications are daily being made.

166. But perhaps the most wonderful application of electricity to the purposes of life is the facility it affords to persons, separated by hundreds of miles, to hold instant communication, by night or by day, giving them the power, as it were, to annihilate space (134), enabling them to consult, admonish, inform, condole with each other, as if they were in the same room, and, having ended their conversation, to turn aside, and one to find himself in London and the other in Edinburgh. There is nothing in fiction more wonderful than this; yet the means are apparently so inadequate, resting as they do,—first, upon the simple principle discovered by Œrsted, in 1819, that a magnetic needle, free to rotate about its centre, when brought near to a wire through which an electric current is passing, tends to place itself at right angles to that wire (144), the direction of its motion following a certain law; and, secondly, that a piece of soft iron is rendered magnetic during the transmission of an electric current along a wire coiled spirally round it, when placed near the wire which connects the poles of a voltaic battery (145).

In the earliest form of electric telegraph a number of magnetic

* By Mr. Woolrich's application of magneto-electricity (146) to electro-plating, the voltaic battery can be altogether dispensed with.

needles were thus arranged at the two extremities of a line of railway, and also at some of the intermediate stations. Each needle had its own wire,* so that any deflection produced on any one needle at any part of the line caused a similar deflection in all those connected with the same wire. Thus, by operating upon two or more wires at once, or in rapid succession, the needles could be thrown into certain positions, which, by previous arrangement, should be made to represent certain symbols, letters, or words. In the latter forms of telegraph, Professor Wheatstone has availed himself of the power of the voltaic current to confer a magnetic condition upon soft iron, which is destroyed the moment the current is suspended or cut off. A number of constant cells is used to convert cylinders of soft iron (2 inches long by ½ an inch in diameter) at the distant station into electro-magnets. Whenever contact is made, the keeper of the magnet is attracted; and when contact is broken, the keeper is removed by a spring. In one form of the instrument, two drivers attached to the keeper act upon a toothed wheel, and convert the alternate into a circular motion, which is transmitted to an axis bearing a signal-disc or *indicator*. In this case the resistance of the wires, as compared with the electromotive powers of the batteries, is not great; but where the resistance is great, the keeper has merely to move a detent which liberates the toothed wheel, and allows motion to be given to the indicator by a clock movement. A *commutator* at one station is furnished with a disc corresponding to the indicator, so that when any sign of one is brought by the hand of the attendant to the place of observation, the corresponding sign is exposed by the other at the distant station. Each station has a commutator and indicator, all four being included

* In this form of electric telegraph, it was thought necessary, in order to close the current, that each needle should be furnished with a return wire; but it has been abundantly proved, by experiment, that water, or even the moisture contained in the earth, is sufficient to transmit the current back to the battery. Hence, in all telegraphic arrangements, the return wire is now dispensed with.

in the one circuit of a wire each way. *Time* may also be transmitted instead of signals, and hence we get what Professor Wheatstone calls the *electric clock*. For this purpose, the indicator is fixed, and furnished with a clock face, the axis carrying an index or hand: the communicating disc is moved round by the oscillations of a pendulum. In this way one good clock can be made to communicate its own time to a series of *skeleton* clocks at any distance.

Various contrivances have been made for *registering* or *printing* the signals. For example, each letter of the indicating disc is attached to a spring radiating from the centre; when the letter is brought, by the action of the instrument, to the proper place for indicating a required signal, a hammer, acted on by clock-work, set free by a second electro-magnet, strikes the letter upon a pad of manifold writing paper and fair paper, and so registers the signal. A cylinder rotating on a spiral axis exposes fresh surfaces of paper. The same current which works these telegraphs also rings an alarum to call attention.

167. *Electricity applied as a moving power.*—The operation of voltaic electricity in magnetizing iron (145), and the disappearance of the excited magnetism directly its action is suspended, or nearly so, has furnished a means of obtaining to a certain extent a considerable moving force applicable to the purposes of machinery; and although in all the attempts hitherto made, engines of great practical value have not been obtained, yet very considerable advances have been made and are still making in electro-magnetic machines.

The general principles resorted to in the construction of electro-magnetic engines are these,—either a rapid change of polarity in masses of iron surrounded by spiral coils, so as to cause them to alternately attract and repel other electro-magnets brought within their influence, or otherwise a rapid magnetizing and demagnetizing of masses of iron in a similar way, without any change of polarity by which an attractive force is brought to act upon other masses of iron, so long

as the attraction is operative in pulling them onward, and no longer. In both these cases a rotatory motion is obtained by fixing the operative masses on the circumference of a wheel, and placing the wheel so as to admit of the action of the electro-magnets upon the extremities of its radii, as in any other similar case of the application of a moving force to the circumference.

Professor Jacobi, of St. Petersburg, by means of an engine on this principle, succeeded, in the years 1838 and 1839, in propelling a boat upon the Neva at the rate of 4 miles an hour. This boat was 28 feet in length, about 7 feet wide, and drew nearly 3 feet water. It contained 10 persons; the engine was worked by a voltaic battery of sixty-four pairs of platinum plates, excited by nitric and sulphuric acid, and propelled the vessel through the medium of paddle-wheels. Mr. Llewelyn exhibited to the members of the British Association, in August, 1848,* a similar experiment on a lake at his beautiful residence near Swansea. By means of an electro-magnetic engine, contrived with singular skill and ingenuity, he propelled a small boat with considerable force through the medium of a screw propeller. Jacobi subsequently applied his engine to working machinery, but not with any great success.

In 1842, Mr. Davidson constructed an electro-magnetic locomotive engine, which was tried on the Edinburgh and Glasgow Railway, the carriage of which was 16 feet in length and 6 feet wide, weighing above five tons, including the batteries and magnets. It was propelled at the rate of about 4 miles an hour.

Wheatstone, Talbot, Hearder, and several others engaged in this branch of science, have given models of electro-magnetic engines which display great powers of invention; and although as yet the perfection of such engines and their practical and commercial advantages remain in great uncertainty, still it is to be considered that the development of

* Meeting of the British Association at Swansea, August, 1848.

the principles upon which they have been constructed is of very recent date, and the question altogether in its infancy. The speed obtained by Professor Jacobi, of 4 miles an hour with a boat on the Neva, certainly exceeded that resulting from the first attempts to propel vessels by steam. We have, therefore, yet to hope for vast improvements in electric machines. When we consider that an electro-magnet lately exhibited in London attracts a mass of iron at one-eighth of an inch distance with a force of 1344 lbs., and requires no less than 4764 lbs. (more than 2 tons) to separate the contact, it is really difficult to assign limits to the application of a moving force derived from the agency of electricity.

THE END.

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